EXAMINING THE EFFECTIVENESS OF THE NIST LABORATORIES

HEARING

BEFORE THE

SUBCOMMITTEE ON TECHNOLOGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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Wednesday, March 20, 2013

EXAMINING THE EFFECTIVENESS OF THE NIST LABORATORIES

WEDNESDAY, MARCH 20, 2013

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 2:01 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Thomas Massie [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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Subcommittee on Technology Hearing

Examining the Effectiveness of the NIST Laboratories

Wednesday, March 20, 2013
2:00 p.m. – 4:00 p.m.
2318 Rayburn House Office Building

Witnesses

Dr. Willie E. May, Associate Director for Laboratory Programs, National Institute of Standards and Technology

Dr. Ross B. Corotis, Denver Business Challenge Professor, University of Colorado at Boulder; Member, Laboratory Assessments Board, National Research Council of the National Academy of Sciences

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON TECHNOLOGY

Examining the Effectiveness of the NIST Laboratories

Wednesday, March 20, 2013
2:00 p.m. – 4:00 p.m.
2318 Rayburn House Office Building

Purpose

On Wednesday, March 20, 2013, the Technology Subcommittee will examine how the work conducted at National Institute of Standards and Technology's (NIST) laboratories is aligned with the promotion of American innovation and industrial competitiveness. The work of the laboratories supports industries such as healthcare, information technology, manufacturing, and construction. The hearing will also solicit recommendations on improving laboratory effectiveness as the Committee considers reauthorizing NIST and its labs.

Witnesses

- **Dr. Willie E. May,** Associate Director for Laboratory Programs, National Institute of Standards and Technology
- **Dr. Ross B. Corotis,** Denver Business Challenge Professor, University of Colorado at Boulder; Member, Laboratory Assessments Board, National Research Council of the National Academy of Sciences

Background

The National Institute of Standards and Technology (NIST) is a non-regulatory agency within the Department of Commerce. NIST's mission is to promote US innovation and industrial competitiveness by advancing measurement science, standards and technology in ways that enhance economic security and improve American quality of life.

NIST activities are primarily housed at two campuses, located in Gaithersburg, MD and Boulder, CO.

In order to advance measurement science, standards, and technology, NIST currently operates six laboratory units, with activities shared across the two campuses:

- **Material Measurement Laboratory (MML):** The MML serves as the national reference laboratory for measurements in the chemical, biological, and material sciences. The MML provides measurement services used by a broad set of industries including but not limited to: healthcare (biomarkers), renewable energy (measuring the quality of fuels) and forensic science (biometric identification techniques);

- **Physical Measurement Laboratory (PML):** The PML develops and disseminates national standards of measurement (e.g., length, mass, force and shock, acceleration, time and frequency, electricity, temperature, humidity and pressure.) This information supports consistent timekeeping, on which many technologies like the global positioning system (GPS) rely, and underpins the safety of our national electricity grid;

- **Engineering Laboratory (EL):** The EL develops and disseminates advanced manufacturing and construction technologies, guidelines, and services to the U.S. manufacturing and construction industries. Examples of EL work include researching ways to reduce the spread of fire in residential buildings and developing performance metrics for advanced manufacturing processes;

- **Information Technology Laboratory (ITL):** The ITL develops and disseminates standards, measurements, and testing for interoperability, security, usability, and reliability of information systems, including cyber security standards, guidelines and best practices for federal agencies and U.S. industry. ITL works in areas such as cloud computing, health information technology, and advanced voting technologies;

- **Center for Nanoscale Science and Technology (CNST):** The CNST provides industry, academia, NIST, and other government agencies with access to nanoscale measurement and fabrication methods and technology. CNST operates a shared-use NanoFab for nanotechnology development;

- **Center for Neutron Research (NCNR):** The NCNR provides a national user facility, utilized by universities, government and industry, to study neutron-based measurement capabilities. NCNR measurement capabilities allow researchers to answer questions in nanoscience and technology with a broad range of applications.

Authorizations/Appropriations

(dollars in millions)

NIST Laboratory Programs	Authorization	Request	Appropriation
FY 2011	584.5	584.5	497.0
FY 2012	661.1	678.9	567.0
FY 2013	676.7	648.0	*

*NIST laboratory activities are currently operating under a continuing resolution, subject to sequestration.

National Research Council Assessments of NIST Laboratories

The National Research Council (NRC) has conducted assessments of the NIST laboratories since 1959.

In 2011, the NRC evaluated three of the six NIST laboratories: the Center for Nanoscale Science and Technology (CNST), the NIST Center for Neutron Research (NCNR) and the Information Technology Laboratory.

The assessments included key findings and recommendations for each of the laboratories.

The NRC recommendations for the CNST included:

- Further diversifying the user base for the NanoFab facility;
- Continuing to increase the CNST focus on industry as its key customer;
- Actively managing the balance between high-quality science and service;
- Continuing the effort to mature the focus and stature of newer research groups; and
- Considering enhancing the professional development of postdoctoral staff by offering opportunities to learn skills needed for non-academic careers – for example, in entrepreneurship.

The NRC recommendations for the NCNR included:

- Taking care that the next generation of senior researchers continues to develop and remain excited about their research;
- Maintaining collaborative efforts with the NIST Material Science Laboratory and the Physical Measurement Laboratory to aid the NCNR in extending its leadership in cold-neutron research; and
- Ensuring that the proposal review process continues to work effectively as the NCNR facility expands to meet greater demand for cold-neutron research capabilities.

The NRC recommendations for the ITL included:

- Considering plans to address the growth that will be needed to support the expanding workload of the Statistical Engineering Division and the Computer Security Division within this laboratory;
- Acquiring a permanent chief of the Advanced Network Technologies Division; and
- Devoting attention to strategic, long-term technical needs in cloud computing.

In 2012, the NRC conducted a Review of Manufacturing-Related Programs at NIST as well as a review of Best Practices in Assessment of Research and Development Organizations.

The NRC recommendations from the Review of Manufacturing Related Programs included:

- Having a process in place that carefully considers industry needs and inputs when selecting and planning the projects to pursue;
- Having a unified programmatic focus, supporting management, and the use of metrics designed to measure progress when coordinating the efforts of multiple, technologically diverse projects; and
- Having more structured coordination among teams across NIST.

Visiting Committee on Advanced Technology

The Visiting Committee on Advanced Technology (VCAT) of NIST was established in its current form by the Omnibus and Competitiveness Act of 1988 (PL- 100-418).

The VCAT's charter includes reviewing and making recommendations on general policy for NIST, its organization, budget, and programs within the framework of applicable national policies as set forth by the President and the Congress.

VCAT members are appointed by the Director of NIST and are comprised of both industry and academic stakeholders. Members are selected for staggered, three-year terms. There are currently 13 members of the VCAT, including 10 members from industry.

The 2012 VCAT Annual Report includes a number of recommendations with respect to NIST laboratories including, among others:

- Increased focus and investment in advanced manufacturing programs;
- Continued NIST research and standards development activities contributing towards the creation of a national public safety communication system;
- Continued strengthening of the planning and integration of NIST measurement services efforts; and
- Greater clarity and depth in strategic planning.

Issues for Examination

The Subcommittee will examine how the NIST labs contribute to NIST's mission of promoting American innovation and industrial competitiveness and how this contribution could be improved. In addition, witnesses have been asked to address how the NIST labs: prioritize project decisions; measure success and set metrics; and work with industry and academic customers.

Witnesses have also been asked to provide recommendations for how NIST can be more efficient and effective as the Committee considers legislative reauthorization.

Chairman MASSIE. The Subcommittee on Technology will come to order. Good afternoon. Welcome to today's hearing, entitled "Examining the Effectiveness of NIST Laboratories." In front of you are packets containing the written testimony, biographies, and truth-in-testimony disclosures for today's witness panel. I recognize myself for five minutes for an opening statement.

This afternoon's hearing is being held to examine the effectiveness of the laboratory programs at the National Institute of Standards and Technology. This hearing will help inform the Committee as it considers reauthorization of NIST and its laboratories later this year.

Measurement science conducted at NIST laboratories contributes to industrial competitiveness by buttressing the technical infrastructure for advancements in nanotechnology, global positioning systems, materials sciences, cybersecurity, health information technology, and a variety of other fields.

Research conducted at NIST laboratories has been lauded by independent outside review panels as being among the best in the world. Indeed, NIST researchers have been awarded four Nobel prizes in physics in the last 15 years.

As the Committee considers reauthorization of NIST, it is important for Committee Members to know whether the research conducted at NIST laboratories is effective. It is also important to understand how NIST prioritizes and coordinates research projects, and how NIST balances its portfolio of research between short-term, lower-risk, lower-reward projects and long-term, higher-risk, higher reward projects.

The National Academies have recently conducted assessments of three NIST laboratories and have conducted a cross-cutting review of manufacturing-related programs at NIST. Dr. Corotis will be summarizing the findings of these recent reviews in his testimony today. While these reviews are mostly positive, they have also identified areas for improvements. The Subcommittee looks forward to exploring the Academies' recommendations this afternoon.

America is currently more than $16 trillion in debt and is running massive deficits on an annual basis. Congress's job is to set priorities. One of the best things we as policy makers can do to improve our economic competitiveness is to get our fiscal house in order. Industry leaders are currently sitting on large cash reserves. They will be reticent to invest that money here in America until they see that the country is on a sustainable path and a sustainable budget.

Just as it is important for our country to prioritize spending decisions, it is also important for our research agencies to do so. We look forward to understanding how NIST can prioritize project decisions in a fiscally responsible manner while contributing to U.S. innovation and competitiveness.

I would like to extend my appreciation to each of our witnesses, Dr. May and Dr. Corotis, for taking time today and the effort to appear before us. We look forward to your testimony.

[The prepared statement of Mr. Massie follows:]

PREPARED STATEMENT OF CHAIRMAN THOMAS MASSIE

Good afternoon, I'd like to welcome everyone to today's hearing, which is being held to examine the effectiveness of the laboratory programs at the National Institute of Standards and Technology. This hearing will help inform the Committee as it considers reauthorization of NIST and its laboratories later this year.

Measurement science conducted at NIST laboratories contributes to industrial competitiveness by buttressing the technical infrastructure for advancements in nanotechnology, global positioning systems, materials sciences, cybersecurity, health information technology, and a variety of other fields. Research conducted at NIST laboratories has been lauded by independent outside review panels as being among the best in the world. Indeed, NIST researchers have been awarded four Nobel prizes in Physics in the last 15 years.

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Just as it is important for the country to prioritize spending decisions, it is also important for our research agencies to do so. We look forward to understanding how NIST can prioritize project decisions in a fiscally responsible manner while contributing to US innovation and competitiveness. I'd like to extend my appreciation to each of our witnesses for taking the time and effort to appear before us today. We look forward to your testimony.

Chairman MASSIE. I now recognize the Ranking Member, the gentlelady from Florida, Ms. Wilson, for an opening statement.

Ms. WILSON. Thank you, Chairman Massie. Thank you for holding this hearing to examine the effectiveness of the laboratory programs at the National Institute of Standards and Technology, and thank you to our witnesses for being here today.

It is essential that we learn more about important work being conducted at NIST's laboratories, as this Subcommittee looks to reauthorize the agency through the *America COMPETES Act*. While I am so pleased to hear from our two witnesses this afternoon, it is unfortunate that we do not have a member from NIST's advisory committee, or VCAT, as it is commonly known, testifying here today. I understand there were scheduling conflicts, but having an oversight hearing without a witness from the group specifically tasked by Congress to review and make recommendation regarding NIST management and policy is regrettable.

NIST is small in size, yet tremendous in impact. For more than 100 years, it has promoted the competitiveness of U.S. industry by advancing measurement, science, standards, and technology. NIST has broaden technical expertise, as well as a unique ability to bridge public and private sector work. The *America COMPETES Act* of 2010 included the first major reorganization of the agency in decades, streamlining NIST's laboratories from ten labs to six. The purpose of the reorganization was to create mission-focused laboratories that were vertically integrated. In other words, a single lab would be responsible for everything from basic research to the delivery of products and services to its customers. VCAT supported the reorganization and reviewed it positively, including acknowledging the importance of the new position of associate director for laboratory programs, a position held by one of our esteemed witnesses, Dr. Willie May.

Since the reorganization is relatively new, it is important that we continue to follow its progress and the activities of the new laboratories. I look forward to hearing how the reorganization is going from the witnesses.

I am also interested in hearing about NIST's cross-cutting research efforts. Under this Administration, it has taken on a prominent role in ensuring that American manufacturers remain competitive in the global marketplace. Manufacturing in the United States has changed from an industry losing jobs to an industry adding jobs, and its activities have the potential to continue that trend by helping manufacturers develop innovative products and processes. I look forward to hearing from the witnesses about the manufacturing programs at NIST, and what, if any, policies that would be recommended to help promote these programs as the Subcommittee discusses reauthorizing NIST.

Another cross-cutting research effort NIST is undertaking is in the field of bioscience. To ensure that countless new biological innovations can be transformed into useful products and services, we need new measurement technologies and standards. I am interested in hearing more about what NIST is doing in this area from our witnesses today. Both these cross-cutting research programs highlight the important work NIST is doing to promote innovation, commercialization, and business growth for our Nation.

In a time when we should be doing everything to ensure our Nation's leadership position in innovation, we are talking about cutting the budgets of agencies like NIST. The *America COMPETES Act* put science agencies, including NIST, on a double funding path so that the United States could maintain its competitive edge, but unfortunately, these levels have not been appropriated. Additionally, sequestration will have real impacts on NIST, including the elimination of grants and contracts, delayed or canceled equipment purchases, and deferred repair and maintenance of NIST facilities. We need to be making smart investments that will help our Nation's economy grow. I hope we will focus on making those needed investments when we reauthorize NIST.

Mr. Chairman, again, thank you for holding this hearing, and I look forward to working with you and our colleagues to ensure that NIST has what it needs to fulfill its important mission.

I yield back the balance of my time.

[The prepared statement of Ms. Wilson follows:]

PREPARED STATEMENT OF RANKING MINORITY MEMBER FREDERICA WILSON

Thank you, Chairman Massie for holding this hearing to examine the effectiveness of the laboratory programs at the National Institute of Standards and Technology, and thank you to our witnesses for being here today.

Today's hearing provides us with the opportunity to review the important work being conducted at NIST's laboratories as part of the Subcommittee's efforts to reauthorize this agency through the *America COMPETES Act.*

Although I am excited to hear from our two witnesses this afternoon, I think it is unfortunate that we do not have a member from NIST's advisory committee—or V-CAT as it is commonly known—testifying here today. I understand there were scheduling conflicts, but having an oversight hearing without a witness from the group specifically tasked by Congress to review and make recommendations regarding NIST management and policy is regrettable.

NIST is a relatively small agency, but is an extremely important player in federal efforts to spur innovation and economic prosperity in this country.

For more than 100 years, NIST has supported the competitiveness of U.S. industry by advancing measurement science, standards, and technology. NIST's broad and deep technical expertise, as well as its ability to serve as a bridge to U.S. businesses, is unparalleled.

The *America COMPETES Act of 2010* included the first major reorganization of the agency in decades, streamlining NIST's laboratories from ten labs to six. The purpose of the reorganization was to create mission-focused laboratories that were vertically integrated so a single lab would be responsible for everything from basic research to the delivery of products and services to its customers.

VCAT supported the reorganization and reviewed it positively including acknowledging the importance of the new position of Associate Director for Laboratory Programs, a position held by one of our witnesses, Dr. Willie May.

Since the reorganization is relatively new, it is important that we continue to follow its progress and the activities of the new laboratories. I look forward to hearing how the reorganization is going from the witnesses.

In addition to learning more about the research and activities happening in each of the six labs, I am interested in hearing about NIST's cross-cutting research efforts.

Under this Administration, NIST has taken on a prominent role in ensuring that American manufacturers remain competitive in the global marketplace. Manufacturing in the United States has changed from an industry losing jobs to an industry adding jobs. And NIST's activities have the potential to continue that trend by helping manufacturers develop innovative products and processes.

I look forward to hearing from the witnesses about the manufacturing programs at NIST and what—if any—policies they would recommend to help promote those programs as the Subcommittee discusses reauthorizing NIST.

Another cross-cutting research effort NIST is undertaking is in the field of bioscience. During the last few decades, we have seen an explosion in biological knowledge-knowledge that has the potential for new cures and treatments for diseases. This exciting time brings along with it new measurement challenges. To ensure those new biological innovations, we need new measurement technologies and standards. I am interested in hearing more about what NIST is doing in this area from our witnesses today.

Both these cross-cutting research programs highlight the important work NIST is doing to promote innovation, commercialization, and business growth for our nation. At a time when we should be doing everything to ensure our nation's leadership position in innovation, we are talking about cutting the budgets of agencies like NIST. The America COMPETES Act put science agencies, including NIST, on a double funding path so that the United States could maintain its competitive edge, but unfortunately those levels have not been appropriated.

Additionally, sequestration will have real impacts on NIST, including the elimination of grants and contracts, delayed or canceled equipment purchases, and deferred repair and maintenance of NIST facilities. We need to be making smart investments that will help our nation's economy grow. I hope we will focus on making those needed investments when we reauthorize NIST.

Mr. Chairman, thank you again for holding this hearing and I look forward to working with you and our colleagues to ensure that NIST has what it needs to fulfill its important mission.

Chairman MASSIE. Thank you, Ms. Wilson.

At this time, I ask unanimous consent to add the NIST Visiting Committee on Advanced Technology's 2012 annual report to the record. Without objection, so ordered.

[The information appears in Appendix II]

Chairman MASSIE. If there are Members who wish to submit additional opening statements, their statements will be added to the record at this point.

At this time, I would like to introduce our witnesses. Our first witness is Dr. Willie May, the Associate Director for Laboratory Programs. In this capacity, Dr. May provides the oversight and direction of NIST's six laboratory programs.

Our second witness is Dr. Ross Corotis, the Denver Business Challenge Professor and the Department of Civil, Environmental, and Architectural Engineering at the University of Colorado at Boulder. He also serves as Chair of the National Research Council Committee on Assessment of NIST's Technical Programs. Dr. Corotis received a doctoral degree in civil engineering with a concentration in structural mechanics from my alma mater, the Massachusetts Institute of Technology.

As our witnesses should know, spoken testimony is limited to five minutes each, after which the Members of the Committee will have five minutes each to ask questions.

I now recognize Dr. May to present his testimony.

TESTIMONY OF DR. WILLIE E. MAY, ASSOCIATE DIRECTOR FOR LABORATORY PROGRAMS, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Dr. MAY. Chairman Massie, Ranking Member Wilson, and Members of the Subcommittee, thank you for the opportunity to testify today. As stated earlier, I am Willie May, Associate Director for Laboratory Programs at the National Institute of Standards and Technology.

Since 1901, NIST, as a non-regulatory agency in the Department of Commerce, has maintained the U.S. national standards for measurement. Our mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life. In carrying out this Congressionally mandated role rooted in the U.S. Constitution, we have been supplying the measurement standards and other tools to help industry innovate and compete for over 100 years. Since our inception, in addition to maintaining the more traditional national standards of measurement, we have focused a significant portion of our research and measurement service activities on addressing contemporary societal needs. We have worked with industry, other government agencies, and the scientific community to ensure that as new measurement standards and technology needs develop, our laboratory program evolves to meet them.

The work of the NIST laboratory program focuses on three primary areas: driving innovation through measurement science, accelerating the adoption and deployment of advanced technology solutions, and providing unique world class, cutting edge research facilities for use by industry and academia.

So how is this accomplished? In three ways, actually. First, we maintain an excellent program in scientific discovery. As stated rather eloquently by one of our former directors, Alan Aston, back in the 1950s, while the development and maintenance of standards provides the first and primary reason for our existence, we recognize that our standards work must keep abreast with expansion of the frontiers of science. In that regard, as stated previously, in the last 15 years NIST researchers have been awarded four Nobel

Prizes in physics. Additionally, we have got—our staff have received the Kyoto Prize in material science, which is essentially the Nobel for material science, two National Science awards, a MacArthur Award, the so-called genius award, the L'Oreal Enesco Women and Science Award, and over 100 other national scientific awards and prizes.

Because of our stature in the community, more than 2,800 collaborating researchers come to NIST each year to work alongside our approximately 1,500 federal scientists and engineers in delivering our mission, giving us a great leveraging effect.

We also address key national priorities. Our capabilities and our technical know-how have us poised to support a number of diverse emerging areas that include advanced manufacturing, additive, bio, nano, advanced materials, smart manufacturing and cyber physical systems, forensics that is providing in science debates for its use in the criminal justice system, and energy efficiency and sustainability.

Two of our best-known current examples of how our expertise in measurements and standard and our expertise in supporting industry has put us in a favorable position to accelerate the transition from world class research to applied solutions and new technology adoption, our work on the smart grid and our work with cybersecurity. With respect to the latter, we recently established a National Cybersecurity Center of Excellence where we bring research done in our laboratories to the private sector so that they can work with us to adopt and implement our standards into their platforms, and supporting the Obama Administration's National Strategy for Trusted Identities in Cyberspace, so-called NSTIC.

We also provide the measurement standards and technology to address our stakeholder needs. This broad research base depends on our delivery of our Standard Reference Materials used to calibrate and validate measurement systems, calibration services where energy sends devices to us to calibrate and Standard Reference Data products. And again, the combination of the three, industry uses these to ensure the quality of their measurements and—development of new products and services.

Looking to the future, we are working to develop so-called NIST on a chip. This will be a suite of portable, highly precise devices that will provide customers with in-place precision measurements and standards needed to keep pace with the ever-accelerating product development cycle. They won't have to then send devices to us to calibrate, which takes time and can be costly. These calibrations will be built into the devices that they use.

In addition, NIST provides industry, academia, and other government agencies with unique user facilities and the accompanying technical expertise that supports innovation in material science, nanotechnology, and other emerging technology areas. Our Center for Neutron Research provides neutron-based measurement capabilities to U.S. researchers from the private sector through providing them access to 30 very unique measurement tools on a merit basis. Our Center for Nanoskill Science and Technology reduces barriers to innovation by providing industry, academia, and other government agencies access to world-class nanoscale measurement and fabrication tools, methods, and technology.

In the few years since its inception, the number of our research participants has grown from zero to more than 1,600. We are currently serving close to 250 different companies in that facility.

Mr. Chairman, in conclusion, the NIST laboratories play a unique role in our Nation's research and technology development enterprise. We sit at the nexus of science and industry, conducting cutting edge world-class measurement science in developing standards that allow industry to innovate and compete successfully in the global economy. I am aware that I have probably not addressed many of the questions that you asked in your opening statement, so certainly thank you for inviting me to testify today, and since time did not permit me to elaborate——

Chairman MASSIE. We will have plenty of questions.

Dr. MAY. Okay.

Chairman MASSIE. That is a wonderful opening statement.

Dr. MAY. I would be happy to address any questions you might have.

[The prepared statement of Dr. May follows:]

Testimony of

Dr. Willie E. May
Associate Director of Laboratory Programs

National Institute of Standards and Technology
U.S. Department of Commerce

Before the
Committee on Science, Space and Transportation
Subcommittee on Technology
United States House of Representatives

"NIST Laboratory Programs"

March 20, 2013

Introduction

Chairman Massie, Ranking Member Wilson and Members of the Subcommittee, thank you for the opportunity to testify today about the NIST Laboratories and the vital role they play in enabling innovation and competitiveness. I am Willie May, Associate Director for Laboratory Programs at the National Institute of Standards and Technology (NIST). NIST is one of our Nation's oldest Federal laboratories and our mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards and technology in ways that enhance economic security and improve our quality of life. Enabling innovation and competitiveness has been an important part of our mission since we were founded as the National Bureau of Standards 112 years ago. In the spring of 1900, when Congress was considering the Act that created the National Bureau of Standards, the accompanying Committee report stated:

> *"...that no more essential aid could be given to manufacturing, commerce, the makers of scientific apparatus, the scientific work of the Government, of schools, colleges, and universities than by the establishment of the institution..."*

That statement is as true today as it was then. From our early electrical measurement research to today's quantum information science, NIST has long been a center for high-impact research meeting the needs of academia, industry, and government.

In today's global economy, the ability of the United States to remain competitive relies increasingly on our ability to develop, manufacture and commercialize innovative technologies. The amount of scientific components in products has increased dramatically. Just think about how much more complex an iPhone is compared to early cell phones, let alone those that hung on everyone's kitchen wall. The ability of America to be technologically innovative both drives and is driven by our ability to observe and to measure. If you cannot measure something, you will not be able to control it. And if you cannot control it, you will not be able to reliably manufacture it. NIST's unique role is to advance measurements and standards to drive innovation and commercialization, thus enabling American industry to remain globally competitive. The important role that NIST plays in supporting innovation and commerce has been recognized time and again with NIST playing central roles in multiple national priorities from manufacturing to cybersecurity. NIST's labs' technological expertise provides the capability to meet these challenges. In my testimony today, I will outline the role that the NIST plays in the areas of measurement science, standards, and technology, as well as some of the significant impacts produced over the past several years.

The NIST Laboratory Programs

Since 1901, NIST has maintained the national standards of measurement, a role that the U.S. Constitution assigns to the Federal government[1], and has been supplying the measurements and tools to help U.S. industry compete successfully. As a non-regulatory agency in the U.S. Department of Commerce, an experienced partner of industry, and the Federal research agency

[1] Article 1, Section 8, Paragraph 5 of the Constitution of the United States accords to the Congress the power to ". . . fix the Standard of Weights and Measures."

specifically focused on promoting U.S. economic competitiveness, NIST is well-positioned to accelerate and promote innovation and advanced technologies through its laboratory programs.

The NIST laboratory programs work at the frontiers of measurement science to ensure that the U.S. system of measurements is firmly grounded on sound scientific and technical principles. Today, the NIST Laboratories address increasingly complex measurement challenges, ranging from the very small (nanoscale devices) to the very large (vehicles and buildings), and from the physical (renewable energy sources) to the virtual (cybersecurity and cloud computing). As new technologies develop and evolve, NIST's measurement research and services remain central to innovation, productivity, trade, and public safety.

The NIST laboratory programs provide U.S. industry, academia, and other Federal agencies with:

- Scientific underpinnings for basic and derived measurement units in the international standards community, measurement and calibration services, and certified reference materials;

- Impartial expertise and leadership in basic and applied research to enable development of test methods and verified data to support the efficient commercialization and exchange of goods and services in industry and commerce;

- Support for the development of open, consensus-based standards and specifications that define technical and performance requirements for goods and services, with associated measurements and test methods for conformity; and

- Unique, cutting-edge user facilities that support innovation in materials science, nanotechnology discovery and fabrication, and other emerging technology areas through the NIST Center for Neutron Research, which provides world class neutron measurement capabilities to the U.S. research community, and the NIST Center for Nanoscale Science and Technology, which supports nanotechnology development from discovery to production.

The efforts of the NIST laboratories are focused on three primary mission areas:

- Driving innovation through measurement science
- Accelerating the adoption and deployment of advanced technology solutions
- Providing world-class, unique, cutting-edge research facilities

NIST carries out its mission with staff that includes some of the world's foremost experts in the measurement science field. In the last 15 years, researchers at NIST have been awarded 4 Nobel prizes in Physics, Kyoto Prize in Material Science (an international Nobel level prize for non-Nobel awarded categories), 2 National Medals of Science, a MacArthur "Genius" Award, over 100 other national scientific awards annually among other recognitions. Because of the caliber of expertise of the NIST research staff, more than 2,800 collaborating researchers come to NIST each year to work alongside our researchers and assist NIST in the delivery of our mission. We are proud of the work we do and continually strive to provide cutting edge research in measurement science to industry.

Driving Innovation through Measurement Science

NIST creates the infrastructure necessary to measure the performance and quality of products and services. In close cooperation with industry, academia, and other Federal agencies, NIST continually advances measurement science, develops standard protocols and test methods, and evaluates and generates data. These critical tools, which the private sector cannot provide due to the high cost and unique skills needed, are the foundations for interoperability between products and systems, enabling global trade.

Industry relies on NIST for the physical measurements and standards needed to enable advanced manufacturing, to develop and test new materials, to enable innovation, and to ensure compliance with regulations. NIST measurement research facilitates the diffusion of precision metrology into industry in a number of ways. Frequently, NIST researchers will develop the next-generation of measurement techniques that are adopted by industry and integrated into commercially available devices, such as scanning probe microscopes, mass spectrometers, and other high precision instruments.

In addition, NIST provides measurement and calibration services via its Standard Reference Materials®, calibration services, and Standard Reference Data programs. Certified reference materials are made available to industry, academia, and throughout the world on a cost-recovery basis, to assure the accuracy of measurements made daily throughout the United States. The calibration services NIST provides help customers achieve the highest measurement quality and productivity. NIST Standard Reference Data are well-documented numeric data used in technical problem-solving, research, and development. Looking to the future, NIST is working to develop a suite of portable, highly-precise devices that will provide customers with "in place" precision measurements to keep pace with ever-accelerating product development cycles. These chip-scale devices will be capable of being directly integrated into equipment and products to provide continuous quality control and assurance, freeing customers from complex measurement traceability chains and lengthy calibration procedures.

Examples of NIST work in this space include:

- **Solving biological measurement problems** -- NIST is ideally positioned to work with industry and Federal regulatory agencies to develop innovative solutions to biological measurement challenges that will enable more efficient manufacturing and quality assurance processes. Biotech drugs, currently dominated by protein therapeutics, are the fastest-growing class of pharmaceuticals, as well as one of the fastest-growing categories of health care-related spending. NIST is developing measurement methods, protocols, and standards for improved characterization of biologic drugs throughout the manufacturing process. For example, NIST researchers are creating mass spectral methods and reference data including peptide libraries to enable more accurate characterization of manufactured protein drugs, and to aid biopharmaceutical researchers in their development of new protein therapies. In support of and in collaboration with industry through the nSOFT consortium, NIST is also developing unprecedented capabilities in determining structure of protein therapeutics based on neutron scattering techniques. This will allow the manufacturers to more accurately assess the quality and uniformity of the medicines produced in the manufacturing process to enable their acceptance. Other bioscience efforts at NIST are targeted at providing measurement science and standards to support new technologies, such as ultra-high throughput- DNA sequencing, and the development of standards to support improved genetics-based disease diagnostics and therapies. By partnering with other Federal agencies including the National Institutes of Health and the Food and Drug Administration, the bioscience research program at NIST supports the new tools, standards, and approaches needed to support science-based regulatory decision-making and to create a flourishing environment for innovation in industry.

- **Pushing the frontiers of quantum science** -- Researchers at NIST are continually pushing the boundaries of advanced, cutting-edge metrologies that can be applied to problems of national significance in a broad spectrum of areas including advanced telecommunications, defense, electronics, energy, environment, health, lighting, manufacturing, microelectronics, radiation, remote sensing, space, and transportation. In one such area, quantum-based communication and measurement systems that use novel quantum states of light are being developed worldwide. However, the technologies used to generate, manipulate, and detect these states of light are inadequate for many emerging applications. NIST research in this field focuses on the development of single-photon technologies for quantum information science and technology. Key projects involve investigating the use of nonlinear fibers and nonlinear crystals as a source of correlated photon pairs or "squeezed light," and then manipulating the squeezed light in new ways to enhance precision measurements, as well as computing and communications based on quantum physics. In addition to creating these non-classical states of light, NIST builds detector systems that are the best in the world at operating at the single photon level. Major recent accomplishments by NIST researchers in this program include demonstrations of the highest system detection efficiency for single photons (greater than 95 percent at 1550 nanometers; world-record, long-distance quantum key distribution systems using superconducting nanowire single-photon detectors; and the first ever time-correlated single-photon counting with superconducting single- photon detectors.

Helping Manufacturers Succeed in the Global Economy

NIST customers span the full range of industries, from established—such as automotive, aerospace, microelectronics, and heavy equipment—to emerging, including nanotechnology and biomanufacturing, across the NIST laboratory programs. The NIST laboratory programs heavily leverage partnerships with major industry and other stakeholders to help guide and inform the development of research programs. Advanced manufacturing is an important component of the NIST laboratory programs, and is ideally positioned across a number of emerging areas of potential opportunity:

- <u>Biomanufacturing</u> — Working closely with industry, the FDA, and consensus standards organizations, NIST is able to provide a supporting measurement infrastructure needed to gain detailed understanding of biomanufacturing processes and to design superior methods that yield higher-quality protein therapeutic products. Next-generation sequencing technologies promise to yield new discoveries for rapid disease detection and reveal potential pathways for the manufacture of biologically-based products including fuels and chemicals. NIST efforts to develop needed SRMs® and validated protocols will be critical to underpin the use of sequencing technologies.

- Nanomanufacturing — NIST will continue to help companies overcome technical barriers to cost-effective, high-volume manufacturing of materials, devices, and systems that exploit the exceptional properties exhibited at nanoscale levels. NIST efforts include measurements and standards to help companies and regulatory agencies address potential environmental, health, and safety risks of nanotechnology-based products.

- Advanced Materials Modeling and Simulation – NIST plays an important role in the interagency Materials Genome Initiative, which has the goal of significantly reducing the time from discovery to commercial deployment of new materials. Through considerable interactions with industry and academia, NIST is developing and deploying needed data infrastructure, including data assessment and validation as well as data standards, and modeling and simulation tools to support advanced material development in the U.S.

- Smart Manufacturing and Cyberphysical Systems – Exploiting advances in sensors, data analytics, modeling and simulation, smart manufacturing integrates these technologies to improve performance at all levels. NIST is developing measurements and standards for automated in-process quality monitoring and control for factory-level production systems. Ultimately these efforts aim to speed development, adoption, and integration of leading-edge intelligent technologies to advance U.S. manufacturing and construction performance and the quality and durability of its cyberphysical infrastructure, such as transportation systems, smart grid, two-way power networks, and remote medical monitoring, diagnostic, and treatment capabilities.

- Energy Efficiency and Sustainability – Several programs are in place to help prepare for future measurement and standards in the area of energy efficiency in manufacturing. The recently completed NIST Net Zero Energy Residential Test Facility will allow researchers to test various high-efficiency and alternative energy systems, materials, and designs. NIST is developing sustainability metrics for manufacturers through activities including methodologies for sustainable processes and resources and the integration infrastructure for sustainable manufacturing. The methodologies characterize unit manufacturing and assembly processes, including supplier capabilities, enabling industry-level manufacturing assessments to improve production efficiency.

Accelerating the adoption and deployment of advanced technology solutions

Technology is rapidly evolving to integrate new capabilities across the economy, including manufacturing processes, transportation systems, critical infrastructure, and healthcare. While these innovations will contribute to the U.S. economy and quality of life, they also present associated challenges in interoperability, security, and resiliency. NIST programs respond to these challenges through the development of standards, prototypes, and guidelines, established through engagement with government and industry users and stakeholders. NIST's expertise in measurements and standards, and its experience supporting industry, accelerate the transition from world-class basic research to applied solutions. To support this transformation, NIST provides test-beds, testing and validation methodologies, support for certification, and support for the development of standards that are essential for the adoption and dissemination of new technologies into wide-spread use in areas such as smart grid, cybersecurity, cloud computing, cyber-physical systems, and smart manufacturing, to name a few.

Smart Grid: NIST's involvement in the smart grid is a prime example of how NIST combines its core research capability with extensive stakeholder engagement to drive technology adoption. The smart grid is a planned nation-wide network that uses information technology to deliver electricity efficiently, reliably, and securely. As outlined Section 1305 of the Energy Independence and Security Act of 2007 (Public Law 110-140), NIST has "primary responsibility to coordinate the development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems." NIST initiated the Smart Grid Interoperability Panel (SGIP) to support NIST in coordinating standards development for the smart grid. The SGIP is a public-private partnership that defines requirements for essential communication protocols and other common specifications and coordinates development of these standards by collaborating organizations, enabling NIST to solicit input and cooperation from private and public sector stakeholders in developing the smart grid standards framework.

Cybersecurity: NIST is a recognized world leader in cybersecurity, with a track record of accelerating the development and deployment of cybersecurity solutions and standards that are reliable, usable, interoperable, and secure, as well as the measurements and standards infrastructure for emerging cybersecurity applications. Some of NIST's recent accomplishments in this area include

- The National Cybersecurity Center of Excellence (NCCoE) -- In FY12, NIST established the NCCoE and completed several steps towards becoming operational, including the establishment of temporary laboratory and office facilities at the joint NIST and University of Maryland Institute for Bioscience and Biotechnology (IBBR). The Center identified initial use cases in the areas of Healthcare Technology and manufacturing and began establishing key partnerships with industry to advance the development of solutions in these areas. The NCCoE will encourage the rapid adoption of advanced security technology by private sector companies, by bringing together experts from industry, government and academia to identify and solve some of today's most pressing cybersecurity challenges.
- The National Strategy for Trusted Identities in Cyberspace (NSTIC) – NIST is playing the lead role in implementing the Administration's strategy by facilitating the creation of an Identity Ecosystem that gives participants access to secure credentials and increases the opportunities for trusted on-line transactions. As part of this effort on September 20, 2012, the NSTIC National Program Office at NIST awarded more than $9 million for five pilot projects in support of the Identity Ecosystem.

World class, unique, cutting-edge research facilities

Industry, academia, and other government agencies have access to unique NIST user facilities that support innovation in materials science, nanotechnology, and other emerging technology areas. The NIST Center for Neutron Research (NCNR) provides world-class neutron measurement capabilities to the U.S. research community, and the NIST Center for Nanoscale Science and Technology (CNST) NanoFab facility supports nanotechnology developments from discovery to production. The customer-focused mission of both NCNR and CNST includes the safe and reliable operation of the facilities, as well as the development and application of entirely new and cutting-edge measurement and fabrication techniques.

NIST Center for Neutron Research (NCNR): The NCNR develops, delivers and maintains world-class neutron measurement capabilities and applies them to science and engineering problems of national interest. The NCNR is operated as a major national user facility with merit-based access made available to the entire U.S. scientific and technological community. In a typical year, more than 2,200 research participants, representing some 42 states, 32 government agencies, and 46 U.S. corporations, utilize the NCNR for neutron measurement studies. Between 1998 and 2007, these users contributed over 2,500 high-impact research papers to the open scientific literature.

Neutrons are powerful probes of the structure and dynamics of materials, and can be used to study a range of material behavior, ranging from molecules inserted into membranes simulating cell walls to protons migrating through fuel cells. The NCNR's neutron source provides the intense beams of neutrons required for these types of measurements. Neutron-based research covers a broad spectrum of disciplines, including engineering, biology, materials science, polymers, chemistry, and physics. Some highlights of the work at the NCNR include:

- Neutron-based tools developed at NIST are being utilized to probe the structure and behavior of new materials at the nanoscale, making it possible to improve process technologies and develop new materials applications ranging from light-weight advanced materials for the auto industry to novel nanocomposites for polymer-based solar cells to innovative materials and approaches for the efficient energy storage.

- Measurements using neutrons are probing internal stresses in materials such as pipelines, turbine blades, railroad rails, and shock absorbers in order to understand and improve the performance of products used in industry, transportation, and national defense.

- In studies of the structure and motions of very large biological molecules such as proteins, NIST is using neutrons to probe the bending and folding properties essential to protein function. The insights gained could lead to the development of new drug therapies, new anti-toxins, and improved vaccines.

NIST Center for Nanoscale Science and Technology (CNST): The CNST user facility was created to reduce barriers to innovation by providing industry, academia, and other government agencies with access to world-class nanoscale measurement and fabrication methods and technology. The unique CNST operating model is designed to support both the current and future needs of the national nanotechnology enterprise. The shared-use NanoFab facility provides convenient, rapid access to a comprehensive, state-of-the-art commercial tool set for nanoscale measurement and fabrication. Looking beyond the current state of the art, the CNST

NanoLab creates the next generation of nanoscale measurement instruments and methods, which are made available through to the scientific community through collaboration.

In the few years since its inception, the CNST has become a major national resource for nanoscale science and the development of nanotechnology. The number of research participants at the CNST is increasing rapidly, exceeding 1,600 in FY 2012 (the fifth full year of operation), and continues to grow. The research participants represent diverse communities, including over 350 institutions from 39 states and the District of Columbia. CNST projects resulted in 160 publications and patents in FY2012, and helped more than 120 companies meet their measurement and nanofabrication needs.

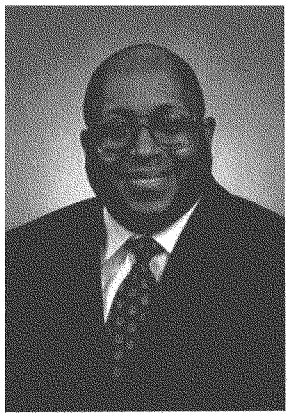
Within the CNST, the NanoFab facility is a world-class, 5,600 square meter (60,000 square foot) shared resource for nanofabrication and measurement – with more than 1,800 square meters (19,000 square feet) of cleanroom laboratory space and more than 85 major commercial measurement and processing tools. To meet specific needs of industry, the NIST NanoFab has created a quick and easy process for researchers to obtain equitable access to the equipment. Research at the NanoFab can be carried out by individual users or with the assistance of a technical expert from the NanoFab staff, imparting the flexibility needed to satisfy the widest range of needs, from expert academic researchers to small companies with an innovative new technology but limited expertise in nanofabrication. Within the next three years, the NanoFab will add a variety of new commercial tools, including those for automated, reproducible lithography; wet chemical processing; and nanoscale patterning and chemical analysis of metals and other hard materials.

Recent highlights of work in the CNST include:

- NIST research is helping uncover the nanoscale structural changes that occur inside an individual nanowire battery during charging and discharging, providing valuable information for improving the efficiency and performance of future rechargeable power sources being developed based on nanowire technology. Scientists at CNST NanoLab have fabricated complete, functional single-nanowire lithium ion batteries optimized for characterization in a transmission electron microscope.

- Access to the CNST NanoFab facility is accelerating important technology developments, including a new method to make precisely shaped holes in diamond, potentially leading to long-lasting micromachines. Research participants from industry are using the NanoFab to develop key chemical modifications needed to make nanoparticles that are 10 times more effective for use in a commercial medical diagnostic system, and to create a novel nanoscale measurement device to spur the development of fuel cell power sources.

Mr. Chairman, in conclusion, the NIST laboratories play a unique role in our Nation's research and development enterprise. NIST sits at the nexus of science and industry, conducting cutting-edge, world-class measurement science and developing standards that allow industry to innovate and compete in the global economy. Ensuring that our researchers have the facilities and resources necessary to keep advancing the critical measurements that will enable U.S. industry to develop the most advanced and best products and services is the top priority for NIST. Thank you for inviting me to testify today. I would be happy to answer any questions.



Dr. Willie E. May is the NIST Associate Director for Laboratory Programs. He is responsible for oversight and direction of NIST's six laboratory programs and is the principal deputy to the NIST Director. The position of Associate Director for Laboratory Programs was created in October 2010 as part of the first major realignment of NIST programs in more than 20 years.

NIST's six laboratories include the Physical Measurement Laboratory, Material Measurement Laboratory, Engineering Laboratory, Information Technology Laboratory, the Center for Nanoscale Science and Technology, and the NIST Center for Neutron Research. The NIST Laboratories collaborate with U.S. industry and universities to conduct measurement, standards, and technology research that advances the nation's R&D infrastructure. The overarching goal of the NIST laboratory programs is to accelerate U.S. innovation, which is a major driver of economic growth and job creation.

Prior to his current position, Dr. May served as Director of the Material Measurement Laboratory, which serves as the Nation's reference laboratory for measurements in the chemical, biological, and materials sciences through activities ranging from fundamental research in the composition, structure, and properties of industrial, biological and environmental materials and processes, to the development and dissemination of certified reference materials, critically evaluated data, and other measurement quality assurance programs.

Previously Dr. May led NIST's research and measurement service programs in chemistry-related areas for more than 20 years. His personal research activities were focused in the areas of trace organic analytical chemistry and physico-chemical properties of organic compounds.

Other National and International Responsibilities: Dr. May has several leadership responsibilities in addition to those at NIST. He is Vice President of the 18-person International Committee on Weights and Measures (CIPM), Chairs the CIPM Consultative Committee on Metrology in Chemistry's Organic Analysis Working Group; Co-Chair's the Joint Committee on Traceability in Laboratory Medicine's Working Group on Reference Materials and Reference Procedures; Chairs the Executive Board for the Hollings Marine Laboratory in Charleston, SC.; and on the Board of Visitors for the University of Maryland College Park's College of Computer, Mathematical, and Natural Sciences.

Honors and Awards: Department of Commerce Bronze Medal Award, 1981; National Bureau of Standards (NBS) Equal Employment Opportunity (EEO) Award, 1982; Department of Commerce Silver Medal Award, 1985; Arthur Flemming Award for Outstanding Federal Service, 1986; NOBCChE Percy Julian Award for Outstanding Research in Organic Analytical Chemistry and Presidential Rank Award of Meritorious Federal Executive, 1992; Department of Commerce Gold Medal, 1992; American Chemical Society Distinguished Service in the Advancement of Analytical Chemistry Award, 2001; Keynote Speaker for the 2002 Winter Commencement Ceremonies, University of Maryland, College of Life Sciences; Council for Chemical Research Diversity Award, the NOBCChE Henry Hill Award for exemplary work and leadership in the field of chemistry, Science Spectrum Magazine Emerald Award in 2005, the 2007 Alumnus of the Year Award from the College of Chemical and Life Sciences at the University of Maryland, member of first class of inductees into the Knoxville College Alumni Hall of Fame in 2010 and Fellow of the American Chemical Society in 2011; Honorary Doctor of Science and Speaker at Graduate School of Arts and Sciences Commencement Exercises, Wake Forest University in 2012.

Chairman MASSIE. Okay, thank you, Dr. May.

I now recognize Dr. Corotis for five minutes to present his testimony.

TESTIMONY OF DR. ROSS B. COROTIS, DENVER BUSINESS CHALLENGE PROFESSOR, UNIVERSITY OF COLORADO AT BOULDER; MEMBER, LABORATORY ASSESSMENTS BOARD, NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMY OF SCIENCES

Dr. COROTIS. Chairman Massie, Ranking Member Wilson, and Members of the Subcommittee, it is my pleasure to address you today and comment regarding the quality of the NIST laboratories.

As stated, I am Dr. Ross B. Corotis, Chair of the NRC Committee on NIST Technical Programs, an elected member of the National Academy of Engineering, and an endowed professor at the University of Colorado in Boulder.

As you know, Congress mandates the NIST Visiting Committee on Advanced Technology, VCAT, focusing primarily on the NIST portfolio and asking, "is NIST doing the right things?" VCAT members are selected by NIST. The NRC committee, on the other hand, is voluntarily engaged by NIST and responsibility for its membership, activities, and reports lies completely with the National Academies. The NRC assessment of NIST laboratories has been provided since 1959, and basically addresses the question, "is NIST doing things right?" It operates with separate panels of technical experts for each laboratory and center assessed, and has no interaction or reporting relationship with VCAT.

Eight years ago, NIST replaced the NRC annual laboratory reviews with biennial ones, and eliminated the overall summary report that identified findings spanning the separate laboratories. About a year ago, NIST asked the NRC to assess the assessment process itself. This study concluded that the peer assessment of quality conducted by the NRC was a crucial and vital part of the overall assessment strategy. Indeed, the report concludes that both the VCAT and NRC aspects of assessment are critical. The report develops guidelines for assessment in three broad areas: management, the quality of scientific and technical work, and relevance and impact. NIST fulfills a unique nexus mission, promoting private industry competing in a world market. The following statement from a Committee report of a few years ago remains valid today. "NIST carries out in a superb fashion an absolutely vital role in supporting, as well as facilitating, the further development of the technological base of the U.S. economy. The personnel and scientific programs of its measurement and standards laboratories are among the best in the world."

I will quote briefly on the three laboratories mentioned from the 2010 and 2011 reports. "Within the United States, there is no other national laboratory or facility that focuses on the missions of the NIST physics laboratory, and there is no other laboratory worldwide that has had the successes in physics that this laboratory has achieved over the past two decades." There has been no assessment, however, of the new Physical Measurements Laboratory since it was formed in 2010. Another quote—"The information technology laboratory's special publication series provides guidelines that are frequently adopted voluntarily in private sector procurements and practices." And another, "The Center for Nanoscale Science and Technology founded in May 2007, is maturing impressively as a state-of-the-art nanoscience and nanotechnology center of excellence, aligned with the overall mission of NIST." All of the CNST facilities are among the best in the world, and in many cases, they are unique.

We are all aware of exceptional capabilities NIST demonstrated after the events of September 11, 2001. Their two-volume CD on the World Trade Center events is the authoritatively detailed account of exactly what happened to the buildings that day. The establishment by Congress of NIST as the home for the National Construction Safety Team Act is indicative of the vital and essential role NIST fills in our country.

Now, addressing the issue of whether NIST could increase its effectiveness in promoting U.S. innovation and industrial competitiveness, I can only note historical challenges in managing cross-cutting programs. The recent review mentioned of manufacturing related programs provided a welcome and promising outcome, and it would be interesting to see whether the expanding biosciences program as mentioned is also following a sustainable trajectory.

And finally, my recommendations to the Committee are to authorize NIST again at the fullest funding possible, and to encourage NIST to avail itself of the continued benefits of the NRC assessments, including 1) performing cross-cutting reviews as well as laboratory reviews; 2) reinstating the practice of examining findings from individual reviews to create a summary report; and finally 3) reestablishing and maintaining a formal, regular interaction between the NRC and the VCAT teams.

Again, I very much appreciate the opportunity to share with you today the findings of the NRC assessment process for NIST, and I would be happy to take the Subcommittee's questions. Thank you.

[The prepared statement of Dr. Corotis follows:]

Statement of

Ross B. Corotis, Ph.D.
Denver Business Challenge Professor
Department of Civil, Environmental & Architectural Engineering
University of Colorado at Boulder
and
Chair, Committee on NIST Technical Programs
Laboratory Assessments Board
Division on Engineering and Physical Sciences
National Research Council
The National Academies

before the

Subcommittee on Technology
Committee on Science, Space, and Technology
U.S. House of Representatives

March 20, 2013

Summary

The Visiting Committee on Advanced Technology (VCAT) focuses primarily on the NIST portfolio, asking, "Is NIST doing the right things?" VCAT members are selected by NIST.

The National Research Council (NRC) committee is voluntarily engaged by NIST, and responsibility for its membership, activities, and reports lies completely with The National Academies. Since 1959 it has addressed the question, "Is NIST doing things right?" It operates with separate panels of technical experts and it has no interaction or reporting relationship with VCAT.

Eight years ago NIST replaced the NRC annual laboratory reviews with biennial ones and eliminated the overall summary report that noted findings common across the NIST laboratories.

Last year NIST asked the NRC to assess the assessment process itself, and it was concluded that peer assessment of quality was a crucial and vital part of an overall assessment strategy. The report develops guidelines for assessment by VCAT and NRC in three broad areas: management, the quality of scientific and technical work, and relevance and impact.

Sample quotations from recent reports:

- "NIST carries out in a superb fashion an absolutely vital role in supporting as well as facilitating the further development of the technological base of the U.S. economy." "The personnel and scientific programs [of its Measurement and Standards Laboratories] are among the best in the world."
- "Within the United States, there is no other laboratory worldwide… that has had the successes in physics that this laboratory has achieved during the past two decades." There has been no assessment, however, of the new Physical Measurements Laboratory since it was formed in 2010.
- "The Information Technology Laboratory's Special Publication series provides guidelines that are frequently adopted voluntarily in private-sector procurements and practices.
- "The Center for Nanoscale Science and Technology [founded in May 2007] now has facilities that are among the best in the world, and in many cases unique."

Recommendations:

- Reauthorize NIST at the fullest funding possible
- Encourage NIST to avail itself of the continued benefits of the NRC assessments, including:
  - Performing cross-cutting reviews as well as laboratory reviews;
  - Reinstating the practice of examining findings from individual reviews to create a summary report; and
  - Re-establishing and maintaining a formal, regular interaction between the NRC and the VCAT teams.

Chairman Massie, Ranking Member Wilson, and Members of the Subcommittee, it is my pleasure to address you today and comment regarding the quality of the laboratories of the National Institute of Standards and Technology, NIST.

I am Dr. Ross B. Corotis, chair of The National Academies Committee on NIST Technical Programs. The National Research Council (NRC) of the National Academies is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, chartered by Congress in 1863 to advise the government on matters of science and technology. My brief background is that I have three degrees from MIT and am founder of the Department of Civil Engineering at The Johns Hopkins University, past Dean of the College of Engineering and Applied Science for the University of Colorado at Boulder, and elected member of the National Academy of Engineering. I served for one year as a Jefferson Science Fellow at the Department of State, and I am currently a chaired professor at the University of Colorado at Boulder.

At the National Research Council of The National Academies I have since 2009 served as the founding chair of the Committee on NIST Technical Programs. Prior to that, I chaired the Panel assessing the Building and Fire Research Laboratory, now part of the Engineering Laboratory, and I was a member of the Board on Assessment of NIST Programs.

Congress mandates that NIST have an oversight committee, called the Visiting Committee on Advanced Technology, or VCAT. The VCAT focuses primarily on the NIST portfolio, or basically, the question "Is NIST doing the right things?" The VCAT members are selected by NIST, and they meet regularly in carrying out their duties to issue an annual report.

The National Academies' committee, on the other hand, is voluntarily engaged by NIST, and responsibility for its membership, activities, and reports lies completely with The National Academies (while seeking NIST recommendations for membership). The assessment of NIST laboratories by The National Academies has been provided for more than half a century (since 1959). Its task is basically to address the question, "Is NIST doing things right?" Therefore it operates with separate panels of technical experts for each laboratory and center assessed, with each panel composed of 15-20 experts from academia, industry, and other scientific and engineering environments, selected to cover the range of activities contained in the particular laboratory or center, with both breadth and depth. This past year none of the laboratories or centers were assessed individually; instead, the committee performed an assessment of the manufacturing-related programs, whose collective activities cut across the NIST laboratories and centers. While the focus of the committee assessment is on the quality of NIST activities, it does this in the perspective of NIST's mission "to promote the U.S. economy and public welfare."

Until eight years ago, The National Academies committee reviewed each NIST laboratory annually and issued reports that summarized its assessment for each laboratory; the reports also included an overall assessment of NIST that summarized findings common across the laboratories. More recently, the committee has reviewed each laboratory every other year, with slight exception, and has issued separate reports on each laboratory or center being assessed. Notably, no overall assessment of NIST has been reported for several years. The National

Academies committee operates completely independently of VCAT and has no interaction or reporting relationship with VCAT.

About a year ago, NIST and VCAT decided that the assessment process itself should be reviewed and assessed. Therefore, NIST contracted with The National Academies to create a study committee. The committee on assessment practices was chaired by Dr. John W. Lyons, a former Director of NIST, the first permanent director of the Army Research Laboratory (ARL), and a Distinguished Research Fellow at the Center for Technology and National Security Policy at the National Defense University. I was a member of that committee, which held several meetings, as well as a workshop of invited participants form the government, private industry, and academia. That committee's task was not focused solely on NIST, but it certainly encompassed agencies such as NIST. It issued a workshop report, as well as a final report, which concluded that the type of peer assessment of quality being conducted by The National Academies was a crucial and vital part of an overall assessment strategy, as was the type of management and policy review being performed by VCAT. Indeed, the report concludes that it is only with both aspects of assessment that an organization can be fully assessed to its greatest advantage. The report develops guidelines for assessment in three broad, crucial areas: assessing management, assessing the quality of scientific and technical work, and assessing relevance and impact. The fact that the assessments conducted by The National Academies are carried out by individuals selected without NIST veto privilege, and that the reports are not made available to NIST for editorial review or approval (although items are provided for fact-checking) prior to public release, further validates the objectivity and independence reflected in the findings of The National Academies assessments by leading experts.

Having been involved in The National Academies assessment of NIST since 1999, I can attest to the overwhelming conviction that NIST is performing vital functions for the United States at a level comparable to or better than the best practices anywhere else in the world. Its unique mission of "providing essential reference data and measurement capabilities to promote the U.S. economy" places it at a crucial nexus for the development and promotion of private industry. It consistently develops standards and advances technology with the goal of enhancing the successful role of private industry to compete in a world market. NIST constantly monitors when its activities promote private industry and public welfare. Standard Reference Material forms an essential underpinning for industry, and to be effective it must be timely and not overly expansive or too restrictive.

The following statements from the committee report of a few years ago remain as valid today: "NIST carries out in a superb fashion an absolutely vital role in supporting as well as facilitating the further development of the technological base of the U.S. economy." "The personnel and scientific programs [of its Measurement and Standards Laboratories] are, by scientific measure, among the best in the world." Two other quotations are germane here: "NIST has undergone a remarkable transformation...from an organization devoted to producing excellent science and standards in an orderly, incremental fashion using a single-principal-investigator mode of operation to an entrepreneurial, outward-looking, customer-focused research organization..." and, "The Board notes, with strong approval, the continued growth of institutional collaborations between NIST and other organizations...[and] balancing its traditional roles in metrology and standards development with its newer, broader roles in technology development related to national needs."

Rather than use my words for the quality of the various laboratories, I quote briefly from the 2010 and 2011 reports of five of the nine individual laboratories. (For consistency and faithfulness to those assessments I will use the separate laboratory titles before the recent reorganization into six laboratories that include two user facilities).

> "The projects reviewed by the Panel on Materials Science and Engineering fulfill the mission of the ... Laboratory. They are formulated well and conducted in generally excellent facilities by an outstanding technical staff."
>
> "The work of the Building and Fire Research Laboratory is of the highest technical quality."
>
> "Within the United States, there is no other national laboratory or facility that focuses on the missions of the NIST Physics Laboratory (now Physical Measurement Laboratory), and there is no other laboratory worldwide working on the physics of standards and technology that has had the successes in physics that this laboratory has achieved during the past two decades."
>
> "The Manufacturing Engineering Laboratory has excellent staff and exceptional facilities. Its work is essential in supporting the NIST mission of promoting U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology."
>
> "The Information Technology Laboratory is a well-managed science and engineering facility contributing in important ways to the nation's scientific and technical research and development needs. The ITL supports the NIST mission through its own mission 'to promote U.S. innovation'."
>
> "The Center for Nanoscale Science and Technology [which was founded in May 2007] has two components with complementary purposes—the research program and the NanoFab facility. It is maturing impressively as a state-of- the-art nanoscience and nanotechnology center of excellence aligned with the overall mission of NIST. All of the CNST facilities are among the best in the world, and in many cases they are unique."

After reading these five glowing reports I feel it is incumbent upon me to mention that no expert serving on a National Academies study committee is allowed to receive any remuneration for participating in the assessments.

A few examples of where NIST makes a difference can be gleaned from the 2010 and 2011 assessments.

For instance, for the Information Technology Laboratory, the assessment report states, "The Digital Library of Mathematical Functions is without peer in the broader community, and the

NIST Special Publication 800* series is renowned for providing technically sound, unbiased, relevant guidelines that are frequently adopted voluntarily in private-sector procurements and practices and often mandated by the Office of Management and Budget for use by the federal government."

For the Materials Science and Engineering Laboratory the Hydrogen Storage project is developing the metrologies necessary for the rapid, high-throughput measurement of the hydrogen content of novel materials proposed for hydrogen storage and for electrodes in nickel metal hydride (Ni-MH) batteries, is addressing computationally critical issues related to the nation's deteriorating highway infrastructure in collaboration with the Federal Highway Administration (FHWA), was the first to develop and certify the Bi2Te3 Seebeck coefficient SRM for the calibration of nanomaterials measurement apparatus, and finally was the first to prove the predictions that a soft FM is forced to reverse by rotating its spins when next to a hard FM (the so-called exchange-spring FM, of interest to DARPA).

The Building and Fire Research Laboratory is addressing computationally critical issues related to the nation's deteriorating highway infrastructure, also in collaboration with FHWA, is a global leader in the realm of understanding material flammability, and in 2005 assumed the leadership of the National Earthquake Hazard Reduction Program, NEHRP.

Within the Physics Laboratory (now Physical Measurement Laboratory), which now houses four Nobel Prize winners, the Ionizing Radiation Division has programs of major importance to national security with performance standards for radiation-detection devices used for the detection of nuclear explosives, and the development of national x-ray standards for security-screening systems for the Department of Homeland Security's Domestic Nuclear Detection Office. The NIST Internet Time Service is used more than 3 billion times every day to synchronize commercial timekeeping devices, helping industry meet Securities and Exchange Commission requirements to synchronize the time-stamping of hundreds of billions of dollars of electronic financial transactions. The Electron and Optical Physics Division forms an important resource for the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration for many different satellite missions. The Physics Laboratory uses its expertise in single-molecule optical detection to elucidate the folding conformational thermodynamics of single ribonucleic acid (RNA) molecules and single DNA molecules in electrophoresis. This information is crucial to understanding RNA-based enzymes or ribozymes and should make it possible to probe the folding and unfolding of biomolecules in chemically active states.

The Center for Nanoscale Science and Technology NanoFab is providing outstanding service with unparalleled capabilities to a broad range of users. Under research, for instance, the experimental effort in the area of laser manipulation of atoms is superb. It is leading to an entirely new method of producing focused-ion beams through laser trapping of metallic atoms using a magneto-optical trap ion source (MOTIS).

And finally, in the Manufacturing Engineering Laboratory, the Precision Engineering Division provides the foundation for dimensional measurements ranging over 12 orders of magnitude (from kilometers to nanometers), developing traceable standards that are crucial to the current and future competitiveness of U.S. industry and the military (for instance, the Laboratory provides unique capabilities assisting the U.S. Army in making measurements of local damage on body armor impacted by projectiles to an accuracy of 0.1 mm).

As these recent reviews attest, the Information Technology Laboratory, the Center for Nanoscale Science and Technology, and the Physics Laboratory, as well as the other laboratories and centers, indicate their tremendous strengths. I should note, however, that there has been no assessment of the Physical Measurement Laboratory, the Material Measurement Laboratory, nor the Engineering Laboratory since they were formed in 2010.

After these accolades, I would like now to take a moment to address the issue of whether NIST could be doing something to be more effective in advancing its mission of promoting U.S. innovation and industrial competitiveness to enhance security and quality of life. The only area in which NIST has not, it appears, had a stellar track record is in managing crosscutting programs. The recent review of manufacturing-related programs provided a welcome and promising outcome, and it would be interesting to see whether the expanding biosciences program is also following a sustainable trajectory.

I would like to highlight the unique position of NIST to step forward and serve this great country when there are unusual situations. I am speaking now most vividly of the events of September 11, 2001. NIST was directed by Congress to do a thorough, complete, technically-based, unbiased investigation into the World Trade Center Disaster. Their two-volume CD, issued in September, 2005, is the excellent, unquestioningly authoritative, detailed account of exactly what happened to the buildings that day. I might add that this is a subject of which I know quite a bit, since my 40-year career has been in the field of structural safety and reliability, and I have chaired the Executive Committee of the International Conference on Structural Safety and Reliability, the American Society of Civil Engineers Committees on the Safety of Buildings and on Probabilistic Methods in Mechanics, the American Concrete Institute's Committee on Structural Safety, and the Live Load Committee for the Minimum Design Loads for Buildings and Other Structures Standard. NIST's role in the investigation of the 9-11 building collapses, and the establishment by Congress in 2002 for NIST to serve as the home for the National Construction Safety Team Act are indicative of the vital and essential role NIST fills for our country.

Finally, my recommendations to the Committee on Science, Space, and Technology, as a representative of the National Research Council's Committee on NIST Technical Programs, is to reauthorize NIST, and to encourage NIST to avail itself of the continued benefits of the NRC assessments, including (1) performing cross-cutting reviews as well as laboratory reviews; (2) reinstating the practice of examining findings from individual laboratory and crosscutting reviews to create a report summarizing overall institution findings common across the individual reviews; and (3) reestablishing and maintaining a formal, regular interaction between the NRC and the VCAT teams.

Again, I very much appreciate the opportunity to share with you today the findings of The National Academies assessments of NIST. I would be happy take the Subcommittee's questions.

Ross B. Corotis, NAE

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Dr. Corotis received both his undergraduate and graduate education at The Massachusetts Institute of Technology, where he was an NSF Graduate Fellow. His degrees are in civil engineering, with an undergraduate minor-equivalent in economics and a doctoral concentration in structural mechanics.

He was on the faculty at Northwestern University for eleven years and then moved to Johns Hopkins to establish the Department of Civil Engineering. In 1994 he became the Dean of the College of Engineering and Applied Science at the University of Colorado at Boulder, and in 2001 returned to the Department of Civil, Environmental & Architectural Engineering as the Denver Business Challenge Professor of Engineering. With a background in structural mechanics and stochastic vibrations, Dr. Corotis' primary research interests are in the application of probabilistic concepts to civil engineering problems, where he has expanded traditional studies of structural reliability into risk and decision modeling for the built environment.

Dr. Corotis has chaired the ASCE Structural Division Committees on the Safety of Buildings and the Technical Administrative Committee on Structural Safety and Reliability, the Engineering Mechanics Division Committee on Probabilistic Methods, the ACI Committee on Structural Safety, and the Subcommittee on Live Loads of the ASCE Minimum Design Loads Standards Committee. He was a member of the CIB Commission on Actions on Structures, the IFIP Committee on Reliability and Optimization of Structures, the Executive Committee of the International Association for Structural Safety and Reliability, the steering committee of the National Research Council's Natural Disasters Roundtable, and past Editor of the journal *Structural Safety* and the ASCE *Journal of Engineering Mechanics*.

He was awarded the ASCE Walter L. Huber Civil Engineering Research Prize in 1984, named Civil Engineer of the Year by the ASCE Maryland Section in 1986, Engineer of the Year by the Baltimore Engineers' Week Council in 1989, Outstanding Engineering Educator by the ASCE Maryland Section in 1992, and is past President of the ASCE Maryland Section. He was named an honorary Distinguished Engineering Alumnus of the University of Colorado at Boulder in 2000, elected to the National Academy of Engineering in 2002, and in 2006 won the Boulder campus teaching award. In 2005 he won the Senior Research Prize of the International Association of Structural Safety and Reliability. He is the chair of the NRC's Committee on NIST Technical Programs, and a member of the NRC Laboratory Assessment Board and the Board on Infrastructure and the Constructed Environment. He is the author of more than 200 publications.

Dr. Corotis is a member of Sigma Xi, Tau Beta Pi, and Chi Epsilon and is both a registered professional engineer (Colorado, Maryland, and Illinois) and structural engineer (Illinois).

Chairman MASSIE. Thank you, Dr. Corotis, thank you, Dr. May. This is a very important meeting today. I appreciate that Members have come here. We have a vote that is now being called on the Floor of the House. It is very important that we do ask questions, though, and so as soon as these votes are over we will return.

At this point, the Committee will recess, subject to the call of the Chair. Without objection, so ordered. Committee stands in recess.

[Recess.]

Chairman MASSIE. The Subcommittee will come back to order. I thank the witnesses for their testimony, reminding Members that Committee rules limit questioning to five minutes.

The Chair would, at this point, open the round of questions. At this point, I am going to recognize Mr. Hultgren for five minutes. Thank you.

Mr. HULTGREN. Chairman, thank you so much, and thank you for the courtesy of allowing me to jump ahead a little bit here. I appreciate that very much.

Thank you both for being here. I apologize for the busy day here on the Hill. There are a lot of different things going on, as you all know, but I appreciate your time and your testimony very, very much.

I do want to address the first question to Dr. May. In 2012, the Visiting Committee on Advanced Technology annual report recommends that NIST provide more clarity and depth in strategic planning. Can you tell us what steps the laboratory programs are taking to improve strategic planning and coordination?

Dr. MAY. Well certainly. Our formal strategic planning process is a work in progress, and I would just like to reiterate that the broad mission that we have and the academic environment that we live in, with multiple stakeholders, requires us to really look at strategic planning in a way that most companies cannot. Essentially, what we have done is—as stated in the VCAT report—is try to capture sort of what we have always done in a rather ad hoc manner; that is, look at our planning first through the lens of national priorities. These are usually short-term needs, and in addition to being poised to address these current needs, we also need to look at building capacity to address future problems.

So addressing the national needs is sort of a top down process, if you will, and then looking at capacity building is more of a bottoms up with our research staff there involved with their research community. They have counterparts in industry, other government agencies, and they bring all that intelligence back to us to determine what type of technical capabilities do we need five, 10 years out, and that begins to drive our recruitment processes to make sure we have the right staff, also to make sure we have the right physical facilities to address needs into the future.

The other lens that we look through that we probably had not paid as much attention to as we maybe could have is sort of how are we looking at aggressing improved internal operations? So we essentially look at it three ways. The shorter term addressing national needs, essentially the here and now, looking at building the capacity to address issues that we foresee coming up in the future, and then looking at changes that we can make to be more efficient custodians of the Nation's resources by improving our internal operations.

Mr. HULTGREN. Okay. Well, thank you. I may have some follow up, if that is okay, just for some more detail, if we can follow up in writing.

But I want to switch gears just with the couple of minutes that I have left, Dr. May. Brain science and medical treatment are very important to me. More and more American families are finding that their kids are being diagnosed with autism. Their parents are being diagnosed with Alzheimer's. I wonder what some of the options are for NIST to improve the environment for research into these afflictions or development of therapeutics to threat them?

Dr. MAY. Well, as you perhaps know, historically NIST has been a physical sciences and engineering laboratory. Certainly over the last decade, we have recognized the importance of expanding into the biological sciences. In fact, I had the responsibility of developing the organizational and strategic plan for our biosciences program. I won't say that we are looking at that issue in general, but we are certainly positioning ourselves to address issues in the biosciences. That particular issue is not on our radar screen yet, but certainly if there is a pull from the biomedical community to identify that as a top priority, we certainly are becoming poised with the right skills and talents to address issues looking at various types of diseases. Right now, primarily our attention is focused on looking at measurement and standards to address genetic diseases and looking at biomanufacturing are our two focus areas. But certainly, we are open to looking at areas such as the one you mentioned.

Mr. HULTGREN. Real quickly, and I only have a few seconds left, but I wonder how about NIST's work with stakeholders and how we on the Committee here can improve the research and development environment through NIST?

Dr. MAY. I guess I didn't quite understand. Can you repeat that, please?

Mr. HULTGREN. Yeah. You know, just wondering with NIST's work with stakeholders and how we on the Committee can insist in improving an R&D environment at NIST, so commitment to research and development. As you mentioned, it is difficult to have very specific—you know what? I see my time is expired. I will follow up with you if we have further questions on that, if that is all right. I just respect the Chairman for deferring to me, so I am going to yield back. I thank the Chairman so much, and we will follow up, if that is okay, with some more——

Dr. MAY. I would be happy to.

Mr. HULTGREN. Thank you so much. Again, thank you both for being here.

Chairman MASSIE. I now recognize Ranking Member, Ms. Wilson, for five minutes.

Ms. WILSON. Wow. Thank you. Thank you so much, Mr. Chair. Thanks to both of you for being here today, and being cognizant of our little schedules, going to vote and coming back. We appreciate it.

This question is—my first question is for you, Dr. May. Bioscience is of particular interest to me, because Florida International University, which is in my district, is partnering with public and private universities, state colleges, and economic development councils to leverage existing regional life science assets in that area of Miami-Dade County. In your testimony, you mention how NIST is ideally positioned to work with industry and federal regulatory agencies to develop innovation solutions to biological measurement challenges. NIST has developed a strategic plan for its bioscience activities. Could you please give us an update on that strategic plan and a review of bioscience related research activities being conducted at NIST currently?

Dr. MAY. Okay. I will give you a very, very high level overview, because to be honest with you, since I moved to my current job I am not as aware of what is going every day in the Material Measurement Laboratory where most of our bioscience related research is going. But back to the strategic plan, I will be happy to send you a copy. The plan that we have, we conducted an outreach activity a few years back where we looked at globally the measurement and standards barriers to innovation in the biosciences. So we looked at this, what are the issues, period. And then from that, we selected a number of areas that NIST would begin to focus on immediately. One of those was providing the measurement on depending to improve the development and regulatory approval of biologic drugs. But if you look at the main pillars of our bioscience program, it is in the area of providing better measurement and standards to support diagnostics, medical diagnostics. The main emphasis now is on genetic diseases. It is to improve the quality of medical imaging, because oftentimes when you have a medical image, you go to one doctor, then you go to another to get a second opinion, and when you really think about it, the truth in that image hasn't changed, it is just an interpretation. So we are trying to put more science in medical imaging so that devices from different manufacturers essentially yield the same truth. And then the other area is working to promote, as I said earlier, the more effective—efficient development and regulatory approval with the FDA of biosimilars of biologic drugs. So those are the three focus areas for our program in bio.

Ms. WILSON. Dr. Corotis, since the bioscience related research activities at NIST are not housed in one laboratory, do you think a review of the bioscience programs by a group like the National Academies is needed?

Dr. COROTIS. Well, I think it would definitely be beneficial. As I had mentioned in my remarks, the cross-cutting programs are always a challenge in any organization, including NIST, and since the biosciences have been ramping up rapidly over the last few years, are a vital contribution that NIST is making and because, as you point out, they are cross-disciplinary across the NIST laboratories, it would seem to me, speaking as an individual, that that would be an ideal area for cross-cutting review. The NRC has done several cross-cutting reviews, manufacturing initiative and before that some others, so it certainly is prepared to do those and if asked, I am sure the National Academies would be happy to put together an appropriate panel to do that.

Ms. WILSON. I don't know if I have time, but in your testimony you recommended that the Committee should reauthorize NIST at the fullest funding level possible. If that is not possible, could you please discuss the tradeoffs that NIST would have to make?

Dr. COROTIS. Well, the one thing that I have noticed is consistent through the history of the reviews—I have been involved for well over a decade—is that there is not what we would call, “fat”. There is not excess there. We have looked at the quality and are very impressed with it. We think that if there is a decrease in the money available, that NIST should—and again, I am speaking as an individual here—should look at what they would have to cut out, which is really a subject matter for VCAT, that looks at what NIST is doing, but that they should cut out some things rather than try and cross the board to continue doing all they are doing, because the quality is very high, but there is no excess of capabilities in there for what they are doing. So not being a member of VCAT or of NIST, I can’t say what they should look at eliminating or what it would be, but I can say that our reports have consistently shown there is just not extra there that could be cut and have them still continue to do the same breadth of programs.

Ms. WILSON. Thank you.

Chairman MASSIE. Thank you, Ms. Wilson.

I now recognize myself for five minutes.

I would like to start out with a general question. What would you say—and I know this is a little bit like asking which one of your children are your favorite children, but what would you say the top three things that NIST does, in terms of the projects or subcategories that they work on—in essence, if you were to prioritize the programs at NIST, what would be the highest priority programs, and could—I would like to ask this of both of you, Dr. May and Dr. Corotis. You can go first, Dr. Corotis.

Dr. COROTIS. I was sure you were going to say Dr. May on that one.

Chairman MASSIE. He was still writing.

Dr. COROTIS. It is hard for me to be too specific at that, because as I say, the National Academies have always been charged with looking at is NIST doing it right, doing the things they are doing right, and so we have always focused on the quality of what they are doing. And there are no programs that we have ever reviewed where we haven’t come away with a very positive feeling about the quality of what they are doing. We have looked primarily at the quality, but we have always been asked to look at its effectiveness for the country, and at the adequate resources for what they are doing. And based on that, there are no programs that we found don’t have the adequate resources to carry it out.

Chairman MASSIE. Let me try and ask the question a little bit differently.

Dr. COROTIS. Okay.

Chairman MASSIE. Let’s say I am going over to vote, which I will do in about 20 minutes here, I think——

Dr. COROTIS. Okay.

Chairman MASSIE. —and I have got three members in the elevator, and I am trying to motivate funding for NIST and I say well, NIST is important because—and we have only got three floors to go.

Dr. COROTIS. Okay, three floors left. Well certainly, it is manufacturing initiatives to work to promote U.S. manufacturing in a global competition. It is extremely important, and they have always been very good at that because there is a time in manufacturing when the government needs to have standards and measurements to enable free competition. And so knowing when to come in and when to step back is something NIST has done very well in manufacturing.

I think in terms of sustainability and safety to U.S. communities, they have done an excellent job, whether investigations of failures, of accidents, of natural hazards, in looking at the importance of long-term planning for the sustainability—and by sustainability, I am talking not just the environmental and the physical, but the economic and social sustainability. All of those are extremely important.

Chairman MASSIE. I think the elevator got to the floor.

Dr. COROTIS. All right. I got to two.

Chairman MASSIE. I appreciate that. The same question, Dr. May, if you could pick three, maybe?

Dr. MAY. I want to answer by saying that we must recognize that we have already—that NIST sees our laboratory programs as being our crown jewels, and we have already seen the elimination of our Technology Innovation Program, and the funding for our biology performance—program go to zero, so that we could infuse those funds into the laboratory program. So we certainly need to maintain them.

And the three things that we do that are critically important is cutting edge measurement science. That is the foundation for everything we do in the laboratory programs. We provide—but again, if we only did cutting edge measurement science, it would be hard to distinguish us from a university or the National Science Foundation. We also provide world-class measurement services to our industry, that is, through our Standard Reference Materials, our Standard Reference Data products, and our calibration programs. It is important that we maintain those.

And the other thing that we provide is access to world-class user facilities where scientists from industry and academia can come in and use our facilities to do things that they would not do, and I have a couple of good examples that I can share with you on that. Talking about a large company, for example, IBM recently came to our Center for Nanoscale Science and Technology because they were trying to divine a next generation chip for some of their devices. Now obviously, they have the money to buy the $2 million piece of equipment that we had; however, they didn't—they thought—they saw it advantageous to come in and use our facility and our expertise of our staff to work with them to see the—if indeed this idea that they had would work so that they could take that back and develop that.

We also had a very, very small company from San Diego who came in and wanted to make essentially a GPS-like device that would operate underground where you have no access to the satellite. Again, they were able to come in. They had an idea, worked with our staff to see if it was feasible, which indeed they did, then they were able to take that back and start developing a process.

And we then actually agreed to actually develop prototypes for them to make sure the manufacturing process is sustainable, so that then they can go back and build a factory and do this. So——

Chairman MASSIE. Thank you for that example. I am glad to hear that at least two of your top three line up with Article 1, Section 8, Paragraph 5 of the Constitution. So you seem to be on mission there with at least two of those.

I now yield five minutes to Peters from California.

Mr. PETERS. Thank you very much, Mr. Chairman, and thank you, gentlemen, both for being here. Dr. May, thank you for helping that company from San Diego. That is my hometown.

Dr. May, I had a question for you. You mentioned in your written testimony that NIST's involvement in the smart grid is a prime example of how NIST combines its core research capability with extensive stakeholder engagement to drive technology adoption. So the Smart Grid Interoperability Panel which you created is a private-public partnership that develops standards for technologies that modernize the electric power grid. So we are going to face that in other kinds of sectors, so I was kind of curious if you would tell us what was the process that you used to incorporate and ensure industry input so that we are working with industry to make sure that you got the appropriate information?

Dr. MAY. Okay, and first of all, let me sort of define standards, because the English language sort of uses the same word to define, at least in this case, two things. In our measurement standards, we are the authority source so we do the measurement to support our measurement standards. For our documentary standards, and we typically use the same word, this is by a consistent process, and the United States actually industry leads our standards making process, and we are simply a facilitator. So with respect to this partnering, we did both. We serve as a convener for the standard—the Smart Grid Interoperability Panel, and actually, we spun that out. We led that effort until it got mature, working with the industry to agree on and adopt documentary standards of protocols and codes that would be useful in the smart grid, and then in our laboratory work, we actually did research in our Physical Measurements Laboratory, primarily to provide the standards—measurement standards that would allow the development and implementation, for example, of smart meters and sensors that would be used on the smart grid. So we use our responsibility as a convener for the development of documentary standards, working with the industry, and then we use our laboratory base measurement activity to develop standards for the devices that would actually operate on the smart grid and conform to these documentary standards that we have developed.

Mr. PETERS. Did any of the stakeholder companies express any concern about sharing their information with NIST or with the other companies that might have been involved, and if so, how did you deal with that?

Dr. MAY. Well obviously people are reticent going in. We, when necessary, can sign nondisclosure agreements, but in this case, that really wasn't necessary. The documentary standards that we develop only work at the sort of pre-competitive level. We are just trying to find out the laws of the land, if you will, and that all players agree to adhere to, and they, in this process, don't usually have to divulge any proprietary information.

Mr. PETERS. When you are doing standards, I suppose that makes sense because it is sort of early in the game.

Do you think that the voluntary standards—the voluntary approach has worked well for NIST?

Dr. MAY. It has worked well. It is the process that we use in the United States. It has stood the test of time.

Mr. PETERS. Okay. I appreciate, again, both of you gentlemen being here. Mr. Chairman, I yield back. Thank you.

Chairman MASSIE. Thank you, Mr. Peters.

We are going to try to do a second round of questions. We have votes coming up, but we will go until the votes are called. At this point, since I am the only Member here on this side, I am going to recognize myself for another five minutes.

Dr. May, you state in your testimony that the NIST laboratory programs worked the frontiers of measurement science, however, according to the National Research Council review of manufacturing related activities at NIST—additive manufacturing research, activities do not constitute the cutting edge in this field and are being phased—being, in fact, being outpaced by industry, according to them. How has NIST responded to this finding, and are there any examples where NIST has found themselves in this position and discontinued projects? Could you describe that?

Dr. MAY. Sure. If—in our laboratory program, if we are not making a positive contribution, we don't have any problem at all to punt, because there are always more problems there than we have resources to address. For example, in our Material Measurement Laboratory, we have cut out—we stopped our program in combustion science to use the resources there to expand our program in atmospheric monitoring. We have reduced some of our efforts that provide grants to support fire research to invest in some of the manufacturing disciplines. So when we don't have critical mass or are not making a significant impact, we routinely reprogram our resources out of one area to strengthen another.

Chairman MASSIE. Thank you for those examples. What about the specific case of additive manufacturing research activities that were identified?

Dr. MAY. We find the strength in that.

Chairman MASSIE. And——

Dr. MAY. In putting more resources into that, and I think it is too early to talk about the success of that. Obviously, we will do our internal evaluation and then we will ask for our next external evaluation, because it is very hard, as you might understand, for us to be totally objective.

Chairman MASSIE. Switching gears here. To what degree is NIST still involved in the smart grid standards?

Dr. MAY. Well, in terms of the laboratory-based research, we are still continuing to do research to improve the quality of meters and sensors that would be used in smart grid. In terms of the Smart Grid Interoperability Panel, that has been spun off and that is being led by the private sector there, and we are just a contributing member of the team.

Chairman MASSIE. Okay. In thinking about the smart grid standard, just to be very specific on this question, is it advance to having some sort of protocol for transmitting the price of electricity to the consumer? For instance, from the power plant to the consumer, do they—is there a protocol or are you——

Dr. MAY. I am not fully aware. I will get that information for you. Certainly, that is the intention down the road. Exactly whether we are there at this point, I really can't say but I will get that information back for you.

Chairman MASSIE. Okay. Thank you, Dr. May.

Dr. Corotis, you mentioned that one of the only areas at NIST that has experienced challenges is in managing cross-cutting research programs. What did the Academies find on this front, and what is NIST doing, in your opinion, to address the challenges?

Dr. COROTIS. Well, that has been the hardest area, as Ranking Member Wilson mentioned also, the cross-cutting ones. The recent report of the manufacturing initiative, which is a cross-cutting one, was very positive. They felt that NIST had, perhaps, through the reorganization of 2009, 2010, been able to look at a higher level across at the cross-cutting activities, and in the case of manufacturing, it was well-coordinated across the newly defined laboratory structure. We haven't yet looked at biosciences. I should say that NIST was interested in having NRC look at the biosciences this past year, but instead focused on the assessment of assessment process and the manufacturing. So we haven't seen yet anything with the biosciences to be able to assess it, but certainly with the manufacturing we saw improvement.

I was involved, oh, maybe eight years ago in a similar cross-cutting in the electronics area where industry was moving so fast the question was could NIST have the nimbleness to really fulfill its mission there, and we had a generally very positive review of that one also, so there certainly are positive examples, but it was difficult in the old structure of laboratories.

Chairman MASSIE. All right, thank you very much.

I am going to yield five minutes to Ms. Wilson for questions.

Ms. WILSON. Thank you, Mr. Chair.

This question is for Mr. Corotis. We all know that VCAT probably should come and give us some input before we go for the reauthorization of NIST, so perhaps at another hearing we can get our Chairman to make sure that they are here. In the meantime, I need to find out how you can help.

In your testimony, you mention how the Visiting Committee on Advance Technology, which is VCAT, focuses on NIST's research portfolio and the National Research Council focuses on how NIST is conducting those research activities. One of your recommendations was that there needs to be more formal and regular interaction between the two groups. Please elaborate on this recommendation, and discuss the current relationship and tell us what you think the future relationship should include.

Dr. COROTIS. Well, thank you very much.

Because NIST voluntarily contracts with the National Research Council to do the assessment, it reports to the NIST administration. It was true that some years ago, the heads of the National Academy review and the VCAT would meet together and even do briefings together, but somewhere along the way that had passed off, and so right now, the National Academies give all the reports to the administration of NIST. And of course, this is NIST's option, since they contract with the National Academies.

As I remember very vividly on September 11 of 2001, I was briefing VCAT on behalf of the National Academies, even though I was not Chair of the Committee at that time, so I remember that day very specially. My personal feeling is that after reading the assessment of assessment study that was done by the Academies, that since those three aspects I mentioned of management, quality, and relevance are so important that it is very hard to separate them into the two categories of is NIST doing the right things and is NIST doing things right? And so it seems to me that, again, speaking only as an individual Chair of this Committee, that for VCAT to hear the results of the NRC studies and share them directly along with management might be part of an overall plan that could be useful for NIST in the long run.

Ms. WILSON. To follow up, NIST asked the National Academies to review the assessment process of research and development organizations. That review led to the report entitled "Best Practices in Assessment Research and Development Organizations," which you discuss in your testimony. You mention how it is important to assess the management, quality of scientific and technical work, and the impacts and relevancy of that work when assessing a research and development organization. How is NIST being reviewed on these three items currently? Could you please discuss how it is being reviewed?

Dr. COROTIS. Yes, thank you. Clearly, the National Academies address the quality of scientific and technical work, and that is the number one thing we look at in all the programs at NIST that are under assessment in any particular year. NIST has also always asked the National Academies, as they always in the past dozen years or so in which I have been involved, to look at the impact of what is done and the relevance. So those two areas have been studied by the National Academies, starting with the quality. We have clearly stayed out of management and strategic planning issues, feeling that came under the purview of VCAT. So we have not offered advice, although once in a while we slip in advice anyway even though we haven't been asked, but we have really stayed out of the management and strategic planning side, although it is hard to keep senior people down. But we really haven't focused on that part, and I think that the best practices study was an excellent one. I did not lead it, although I was a member, and actually a former NIST director was the leader of it who had other government roles and private industry roles, and I think that it says the right thing. You have to start at the management and that was listed first, and then you have to look at the quality of what is being done and then you have to look at the relevance of it. And I think that VCAT comes in at the management and also at the relevance and impact in guiding what programs to do.

Ms. WILSON. Okay. Thank you so much.

Chairman MASSIE. Thank you, Ms. Wilson.

I would like to thank the witnesses today for their valuable testimony and for taking the time to come here and testify. Dr. May, I look forward to coming and visiting there in Gaithersburg very much.

Dr. MAY. We would love to have you.

Chairman MASSIE. I am not sure when I would make it to Colorado, though.

Dr. COROTIS. Maybe for the NCAA final.

Chairman MASSIE. My team won't be there.

But anyway, the record will remain open for two weeks for additional comments and for written questions from Members. At this time, our votes have been called so we are going to end the meeting here. The witnesses are excused, and this hearing is adjourned.

Thank you very much.

[Whereupon, at 3:50 p.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO HEARING QUESTIONS

Answers to Hearing Questions submitted by Dr. Willie E. May, Associate Director for Laboratory Programs, NIST

From the draft transcript of the March 20, 2013, hearing before the House Science, Space, and Technology Subcommittee on Technology regarding *Examining the Effectiveness of the NIST Laboratories*

Chairman MASSIE. Switching gears here. To what degree is NIST still involved in the smart grid standards?

Mr. MAY. Well, in terms of the laboratory-based research, we are still continuing to do research to improve the quality of meters and sensors that would be used in smart grid. In terms of the smart grid interoperability panel, that has been spun off and that is being led by the private sector there, and we are just a contributing member of the team.

Chairman MASSIE. Okay. In thinking about the smart grid standard, just to be very specific on this question, is it advance to having some sort of protocol for transmitting the price of electricity to the consumer? For instance, from the power plant to the consumer, do they--is there a protocol or are you--

Mr. MAY. I am not fully aware. I will get that information for you. Certainly, that is the intention down the road. Exactly whether we are there at this point, I really can't say but I will get that information back for you.

Chairman MASSIE. Okay. Thank you, Dr. May.

Answer:

The NIST Smart Grid Interoperability Panel standards coordination process identified the communication of pricing information to consumers as a key need, along with related communications for demand response and energy usage information. Priority action plans were developed to accelerate standards development in these areas, as described in NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0 and 2.0. These efforts have resulted in several specific outcomes described below.

- The OASIS Energy Market Information Exchange (EMIX) has been published. This standard defines an information model representing price and product information intended to serve as the basis for communication protocol standards that will exchange this information.

- The OASIS Energy Interoperation (EI) standard has been published. This standard defined a communication protocol based on the EMIX model that provides for a wide range of customer interactions including communicating pricing information.

- OpenADR 2.0 is a proposed standard (nearing completion) that represents an implementation of a subset of EI features that specifically relate to demand response (OpenADR refers to Open Automated Demand Response). Demand response in Open ADR 2.0 can be triggered by either price signals or by requests to shed load based on a set of levels. OpenADR 2.0 is a refinement on a previous version that has been used in many field trials in the U.S. and several other countries. It is supported by an industry alliance (OpenADR Alliance) that is beginning interoperability testing of the revised version. Interoperability testing is a necessary first step towards broader implementation.

• Smart Energy Profile (SEP) 2.0 is a proposed standard (nearing completion) that is also supported by an industry alliance (Zigbee Alliance) and is beginning interoperability testing. The distinguishing feature of SEP 2.0 is that it targets the specific environment and constraints of residential consumers.

• Green Button standards, including NAESB Energy Usage Information and Energy Services Provider Interface (ESPI), have been published and are being implemented. These standards provide an energy usage information model and create a standardized process and interface for communicating energy usage information to an authorized third party service provider. These standards provide the foundation for the Green Button Initiative, to enable consumers to more readily access their own energy usage information in a standardized electronic format, which includes options to communicate cost of usage. With early electric utility implementations, over 16 million U.S. customers now have Green Button data access to help them better understand and manage their energy usage. Based on additional utility commitments, the program will grow to include 36 million customers in 2013.

These standards are just emerging, and industry partners are engaged with initial pilot implementations, but more work is needed before applications using pricing information are deployed on a large scale.

In addition, there are important regulatory and policy factors to consider to support large-scale implementation of pricing communications. A strong factor in whether consumers will respond to pricing communication signals is whether they are enrolled in a dynamic pricing or other incentive program, as authorized by an appropriate utility regulator (including time-of-use rates, critical peak time rebates, and other programs primarily implemented at the state level but also relevant for energy markets for demand response at the Independent System Operator level or region). In these programs, customers receive an economic incentive to pay attention to pricing information and respond by reducing use during high cost time periods. An additional factor is the need for customer education.

Appendix II

Additional Material for the Record

SUBMITTED BY CHAIRMAN MASSIE, SUBCOMMITTEE ON TECHNOLOGY

VISITING COMMITTEE ON ADVANCED TECHNOLOGY
National Institute of Standards and Technology

2012 Annual Report

Visiting Committee on Advanced Technology of the National Institute of Standards and Technology

U.S. Department of Commerce

February 2013

VCAT

VISITING COMMITTEE ON ADVANCED TECHNOLOGY
National Institute of Standards and Technology

Preface

The Visiting Committee on Advanced Technology (VCAT) of the National Institute of Standards and Technology (NIST) was established in its present form by the Omnibus Trade and Competitiveness Act of 1988 and updated by the America COMPETES Act. The VCAT is a Federal Advisory Committee Act (FACA) committee and its charter includes reviewing and making recommendations regarding general policy for NIST, its organization, budget, and programs within the framework of applicable national policies as set forth by the president and the Congress. In addition, the America COMPETES Act calls for the VCAT to comment on NIST's three-year programmatic plan in its annual report to Congress. This 2012 annual report covers the period from the beginning of March 2012 through February 2013.

The Committee reviews the Institute's strategic direction, performance and policies, and provides the Secretary of Commerce, Congress, and other stakeholders with information on the value and relevance of NIST's programs to the U.S. science and technology base and to the economy. At the first meeting of each year, the Director of NIST proposes areas of focus to the Committee and agreement is reached on a program for the year. Over the past year, the Committee has been active in assessing NIST's contributions to and progress in the following areas:

- NIST Safety Systems and Safety Culture
- NIST Role in Advanced Manufacturing
- NIST Role in the Public Safety Network
- NIST Centers of Excellence
- R&D Planning
- NIST Budget

The Committee reviews a significant portion of NIST programs through direct discussion with NIST leaders, scientists, and engineers. Reactions and observations of the Committee members are presented candidly to the NIST senior management and other attendees at each meeting. This feedback encourages scrutiny of and continuous improvement in key areas in the overall operation. The Committee also visits various NIST laboratories and satellite facilities to discuss research projects directly with the technical staff. These laboratory tours help the Committee to assess the impact of NIST research, progress towards achieving research goals, the quality of the staff, institutional culture, and the efficacy of the facility infrastructure.

Under the Committee charter, the Director of NIST appoints the VCAT members. Members are selected on a clear, standardized basis, in accordance with applicable Department of Commerce guidance. Members are selected solely on the basis of established records of distinguished service; provide representation of a cross-section of traditional and emerging U.S. industries; and are eminent in fields such as business, research, new product development, engineering, labor, education, management consulting, environment, and international relations. No employee of the Federal Government can serve as a member of the Committee. Members are appointed for staggered three-year terms.

Two new members were appointed during the period covered by this report: William Holt (Intel Corporation) and John Tracy (Boeing Company). During the time of his service, vice-chair Alan Taub transitioned from General Motors to the University of Michigan and Pradeep Khosla moved from Carnegie Mellon to become Chancellor of University of California, San Diego.

This report highlights the Committee's observations, findings and recommendations. Detailed meeting minutes and presentation materials are available on the NIST web site at www.nist.gov/director/vcat.

VISITING COMMITTEE ON ADVANCED TECHNOLOGY
National Institute of Standards and Technology

VCAT Members During the Period Covered by this Report

Dr. Vinton G. Cerf, Chair Google Term: February 1, 2007 - March 31, 2013	Dr. Alan I. Taub, Vice Chair University of Michigan Term: May 9, 2008 - May 8, 2014
Dr. Sujeet Chand Rockwell Automation Term: April 1, 2010 - March 31, 2016	Dr. Uma Chowdhry DuPont (Emeritus) Term: October 1, 2010 - September 30, 2013
Dr. Tony Haymet Scripps Institution of Oceanography, UCSD Term: September 1, 2009 - August 31, 2015	William M. Holt Intel Corporation Term: May 13, 2012 - May 12, 2015
Dr. Karen Kerr University of Southern California Term: June 1, 2011 - May 31, 2014	Dr. Shaygan Kheradpir Barclays Bank Term: April 1, 2010 - March 31, 2013
Dr. Pradeep Khosla University of California, San Diego Term: June 2, 2008 - June 1, 2014	Dr. Roberto Padovani Qualcomm Technologies, Inc. Term: May 1, 2011 - April 30, 2014
Dr. Alton D. Romig, Jr. Lockheed Martin Aeronautics Company Term: April 15, 2009 - April 14, 2015	Dr. Darlene J.S. Solomon Agilent Technologies Term: January 3, 2010 - January 2, 2016
Dr. John J. Tracy The Boeing Company Term: January 7, 2013 – January 6, 2016	

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VISITING COMMITTEE ON ADVANCED TECHNOLOGY
National Institute of Standards and Technology

1. VCAT Focus in 2012

In 2012, the VCAT focused its primary attention on four major NIST issues:

- Safety Systems and Safety Culture at NIST - The VCAT was charged with providing feedback on progress enacting the 2010 recommendation of the Blue Ribbon Commission on Management and Safety II. For additional information, see the scope and charge for the VCAT Subcommittee on Safety (below).
- Advanced Manufacturing - The VCAT was charged with providing feedback on the design of the National Network for Manufacturing Innovation (NNMI). The Committee used recommendations for the Advanced Manufacturing Technology Consortia (AMTech) as a launching pad plus input from the Request for Information (RFI) and regional workshops. The NNMI is a collaboration between NIST, the Department of Defense (DOD), the Department of Energy (DOE), and the National Science Foundation (NSF), and other government agencies to establish up to 15 Institutes for Manufacturing Innovation.
- Public Safety Networks - The VCAT was charged with using its recent report on the Nationwide Public Safety Communications System to address how NIST can best support the Public Safety Broadband Network in the context of the "First Responder Network Authority" (FirstNet) legislation. NIST will coordinate the development of interoperability standards, technologies, and applications to advanced public safety communications, drawing especially on its Public Safety Communications Research program housed at NIST in Boulder, CO.
- NIST Centers of Excellence - The VCAT was charged with sharing its unique experiences in public-private collaborations to help ensure that the mission and goals of the proposed NIST Centers of Excellence are met. The President's FY 2013 budget request included $20 million for up to four Centers of Excellence in measurement science areas defined by NIST for collaborations with academia and industry. This initiative builds on NIST's long-standing and successful partnerships with academic organizations, such as JILA at the University of Colorado, Boulder, and the Institute for Bioscience and Biotechnology Research (IBBR) at the University of Maryland.

This 2012 Annual Report summarizes the VCAT's work and the recommendations adopted and issued by the VCAT in each of the above areas. The report also includes our recommendations on R&D planning at NIST and the NIST budget to the extent possible given the current state of budget discussions in the U.S. government.

In addition, we note with pleasure that during calendar year 2012 the Smart Grid Interoperability Panel (SGIP) was successfully transitioned from an entirely government-funded model to a sustainable model in which the private sector and government share in the funding. Just a few months after beginning operation as a not-for-profit 501(c)3 corporation, nearly 100 companies and organizations have joined as dues paying members of the new SGIP, contributing $800,000 annually in membership dues.

The VCAT was also impressed with the achievements of the Baldrige Performance Excellence Program (BPEP) over the last year, transitioning from a federally-funded program to a fee and Foundation-funded program. The VCAT believes the BPEP is an important contributor to the NIST portfolio and to performance improvement in the United States and should be sustained. In addition to its impact on business, the very high adoption rate in health care can make a significant contribution to health care quality and cost reduction. The VCAT encourages the Department of Commerce to provide support for the Baldrige business model, including its fee-based activities and support from the Baldrige Foundation. Given the public benefit of the program, some level of government support through appropriation and other agencies with compatible missions should not be ruled out.

VISITING COMMITTEE ON ADVANCED TECHNOLOGY
National Institute of Standards and Technology

2. NIST Safety Systems and Safety Culture

In 2012, the VCAT, in consultation with the NIST Director, established a Subcommittee on Safety within NIST to assess and recommend potential improvements. The charge to the subcommittee is shown below:

> ***VCAT Subcommittee on Safety -- Tony Haymet, Chair***
>
> *NIST is working diligently to address the recommendations of the NIST Blue Ribbon Commission on Management and Safety – II (BRC II), which were released in November 2010. In response to these recommendations, NIST has begun to (i) implement a safety, health, and environmental management system; (ii) develop a comprehensive NIST assessment program; and (iii) establish a suite of meaningful safety metrics. The charge to the VCAT Subcommittee on Safety was to:*
>
> - *Assess NIST's progress in meeting senior leadership's commitment to making safety an integral core value and vital part of the NIST culture*
> - *Identify strengths and opportunities for improvement in both approach and direction.*

In the 2010 VCAT report, we recommended that NIST fully implement the recommendations of the NIST BRCII report. The 2011 VCAT report reviewed progress in the four primary recommendations, including (a) the appointment of an Associate Director of Laboratory Programs; (b) demonstration of the commitment to safety from senior NIST management; (c) establishment of an audit mechanism; and (d) a set of safety metrics.

The Subcommittee on Safety met in October 2012 and February 2013 to assess progress toward full implementation of the BRC II recommendations. The subcommittee met with a cross-section of NIST staff, including laboratory directors, division chiefs, organizational unit (OU)/division safety personnel (including division safety representatives (DSRs), and group leaders in Boulder and Gaithersburg. In addition, the subcommittee toured older facilities (Building 2 in Boulder and Building 245 in Gaithersburg) as well as newer facilities (the clean room facility in the Precision Measurement Laboratory in Boulder) in order to observe operating conditions.

During the year covered by this report, the committee also examined NIST's progress toward safety metrics. NIST has established and is currently tracking metrics in (a) establishment of the NIST Occupational Safety and Health Management System (OSHMS); (b) incident reporting and investigation; (c) radiation-safety program implementation; and (d) management of hazardous chemical waste.

2a. Establishment of the NIST Office of Safety and Health Management System

NIST's OSHMS is foundational to Occupational Safety and Health (OSH) management at NIST in that it establishes NIST's OSH requirements, delineates OSH roles and responsibilities, and provides the infrastructure to facilitate safety program implementation and management across the Institute. NIST began tracking progress in this area at the beginning of FY 2012 using (a) the number of draft OSH policies, orders, and suborders approved by the Chief Safety Officer per quarter; and (b) the number of draft OSH policies, orders, and suborders vetted through the NIST Executive Safety Committee (ESC) per quarter. Beginning in FY 2013, NIST will begin tracking the number of OSH program deployment plans vetted through the ESC per quarter, and the number of OSH programs deployed.

2b. Incident Reporting and Investigation

On August 30, 2010, NIST launched its Incident Reporting and Investigation Program and supporting Information Technology application, IRIS, both of which apply to all NIST workplaces. Using the web-based forms provided by

IRIS, NIST OUs can submit incident reports, the results of incident investigations, and "lessons identified" to the Office of Safety, Health, and Environment (OSHE) for posting on the NIST safety website. IRIS also allows NIST staff members to subscribe to receive postings.

In this area, NIST is tracking the following initial set of metrics:

- Number of injuries per month;
- Number of illnesses per month;
- Number of spills/releases per month;
- Number of incidents resulting in property damage per month;
- Number of near misses per month; and
- Number of incidents other than the above per month.

In response to salient features in the data, NIST is now offering courses on machine-shop safety, promoting ergonomics training, and conducting informational campaigns on hand safety and the avoidance of slips, trips, and falls.

On April 1, 2012, and in the spirit of continual improvement, NIST deployed version 2 of the Incident Reporting and Investigation Program, including IRIS, and began tracking the following additional metrics, "making measurements" at the end of every month:

For initial incident reports posted to the NIST safety website during any given month:

- Total number of such reports;
- Number of such reports submitted within two business days of the incident;
- Number of associated incident investigation reports submitted within 20 business days of the incident; and
- Number of associated incident investigation reports not submitted within 20 business days of the incident as of the last day of the last month measured.

For initial incident reports posted at any time prior to the end of any given month:

- Number of associated incident investigation reports at month's end not submitted within 20 business days of the incident.

In addition, NIST is tracking the following two Occupational Safety and Health Administration (OSHA)-defined injury and illness incidence rates:

- Total Recordable Case (TRC) Rate – Number of recordable injuries and illnesses per 200,000 employee work hours (100 employees each working a 2000-hour work year); and
- Days Away, Restricted, or Transferred (DART) Rate – Number of injuries and illnesses of Types 3, 4, and 5 per 200,000 employee work hours.

2c. Radiation-Safety Program Implementation

NIST's radioactive materials license in Gaithersburg requires quarterly audits of radioactive material facilities for compliance with U.S. Nuclear Regulatory Commission regulations and license requirements. Moreover, recent annual external audits have indicated that NIST needs to strengthen its quarterly audit program. As a result, NIST has formalized this program to a great extent and in the third quarter of FY 2012 began to track and communicate audit results to involved NIST management and staff. In addition to audit findings, NIST is also tracking and communicating recommendations and noteworthy work practices. Over time, NIST expects this effort to result in an increased understanding of regulatory requirements, uniformly good work practices, and a significant decrease in the number of findings.

2d. Management of Hazardous Chemical Waste

NIST has developed a formal inspection program for its satellite accumulation areas in Gaithersburg and in the third quarter of FY 2012 began to track and communicate audit results to involved NIST management and staff. Over time, NIST expects this effort to result in an increased understanding of regulatory requirements, uniformly good work practices, and a significant decrease in the number of findings.

OBSERVATIONS:

A culture change toward safety is well underway at NIST. It is moving from the "design-build" phase to one of continual improvement. While NIST has made substantial progress in developing a positive safety culture, the NIST recordable incident data do not yet demonstrate a clear downward trend. The underlying driver of the incidents appears to be high frequency, lower consequence events (rather than low frequency, higher consequence events). This observation may point to a need for an approach to prevention and education activities within the safety system that emphasizes the prevention of more routine incidents such as slips, trips, and falls; body parts struck by or against objects; and ergonomics, including various types of overexertion.

RECOMMENDATIONS:

- NIST's safety goal should be zero accidents. The VCAT encourages continued recognition of and reward for safety improvement.
- The VCAT recommends continued "grand rounds" audits of individual laboratory rooms led by senior, trained NIST executives.
- The VCAT recommends that NIST set a firm target for improvement in each OSHA recordable statistic.
- The VCAT urges the NIST Director to distribute and discuss IRIS statistics each reporting period. Based upon these reports, NIST leadership should identify top priority IRIS issues and action plans to reduce occurrence. Progress will be reviewed as a standing agenda item at the beginning of each VCAT meeting.
- The VCAT recommends that NIST concentrate its investigation time and reports on OSHA recordable incidents.
- The VCAT strongly urges increased "transparency" on all safety metrics, including easily accessible identification of the exact stage at which any non-closed IRIS cases are at any time.

3. NIST Role in Advanced Manufacturing

In 2012, the VCAT continued its focus on Advanced Manufacturing at NIST, but broadened its lens to survey the entire NIST advanced manufacturing portfolio, from conducting basic research to supporting manufacturers with commercial products. Across these programs, NIST is using a number of partnering mechanisms to support engagement with industry (including small and medium sized enterprises), academia, and other government laboratories. The VCAT was specifically asked to consider the following questions:

- Looking across the various programmatic efforts, are there any gaps in the approach to support the NIST mission of promoting U.S. innovation and industrial competitiveness?
- Our current laboratory programs support emerging technologies and systems interoperability issues. From a program growth and focus perspective, are these appropriate areas in which NIST should focus?
- What is required for NIST's portfolio to be adequately positioned to meet challenges associated with near-term and long-term national advanced manufacturing needs?

- Considering congressional support for AMTech at a level of $14.5 million, what steps should NIST take to ensure maximum benefit from this program?

3a. NIST's Portfolio of Programs in Advanced Manufacturing

Enhancing U.S. manufacturing competitiveness through the delivery of measurement science, standards and technology is at the heart of what NIST does, and is called out in the founding documents that established the National Bureau of Standards in 1901. Long-term economic competitiveness is strengthened by the development and deployment of NIST's advanced manufacturing technology capabilities. NIST aligns its research and services with pressing industry needs through partnerships with manufacturers, academic and government laboratories, and through staff participation in more than 1,000 international standards activities.

- **The NIST Laboratories** address increasingly complex measurement challenges, ranging from the very small (nanoscale devices) to the very large (vehicles and buildings), and from the physical (renewable energy sources) to the virtual (cybersecurity and cloud computing). Research at NIST is underway to develop and deliver the measurement science tools that will support advanced manufacturing technologies, including materials modeling and simulation, nanomanufacturing, biomanufacturing, smart manufacturing, robotics, and other enabling technologies.
    - **Measurement science and standards services** developed at NIST provide the basic and applied research underpinnings to support advances in manufacturing. Physical measurement standards are providing traceability to a common, international standards system – through calibration services, lab accreditation, and other means. NIST efforts are vital to pushing the state-of-the-art in materials characterization and providing critically evaluated materials property data, methods, and standard reference materials to industry.
    - NIST provides the enabling **interoperability standards and tools** to allow manufacturers and researchers to lower costs and accelerate innovation. Standards and other guidance tools open up access to information about shop floor equipment, assist in supply chain management, and support the development of a secure cyber infrastructure. NIST is providing industry with support for open, consensus-based standards and specifications that define technical and performance requirements, with associated test methods for conformity. Some NIST standards also have the benefit of enabling interoperability among disparate systems or competitively produced products, enabling consumer choice and multiple sources of supply.
    - **Unique, cutting edge user facilities** support innovation in materials science, nanotechnology discovery and fabrication, and other emerging technology areas through the NIST Center for Neutron Research, which provides world class neutron measurement capabilities to the U.S. research community, and the NIST Center for Nanoscale Science and Technology, which supports nanotechnology development from discovery to production.
    - **Technology and knowledge transfer** from NIST to promote U.S. competitiveness is enabled through various agreements and intellectual property tools such as NIST inventions, patents, and licenses. Visiting scientists and postdoctoral researchers develop technical expertise through research experiences at NIST.

- **Hollings Manufacturing Extension Partnership (MEP)** is supporting technologies and practices that increase the competitiveness and resilience of our nation's small and medium manufacturing base. A federal-state-local partnership, MEP is enabling future growth with a long-term focus on encouraging cultures of continuous improvement, accelerating the adoption of new technology to build business growth, responding to evolving supply chains, implementing environmentally sustainable processes, and supporting a strong workforce.
    - MEP, in partnership with other organizations, is developing the National Innovation Marketplace (NIM) to facilitate connections between original equipment manufacturers (OEMs) and potential

suppliers. Through the NIM, sellers, buyers, investors, and distributors across industries are connected through an approach incorporating training, business opportunity forecasting, and access to manufacturers.

- ExporTech is deployed nationally as a collaboration between MEP, U.S. Export Assistance Centers, and other partners including the Small Business Administration. Helping companies enter or expand in global markets, ExporTech leads companies through a facilitated process.

- **Baldrige Performance Excellence Program** – The Baldrige Program promotes excellence in organizational performance; recognizes the quality achievements of U.S. manufacturers, small businesses, and other types of organizations; and publicizes successful performance management strategies. The program also manages a national award that has become a global standard, and one measure of its importance is the growing number of similar programs throughout the world. *(Note: this program has been eliminated from the NIST budget, having transitioned to a foundation-supported model.)*

PROPOSED Programs in the NIST Portfolio:

- **National Network of Manufacturing Innovation (NNMI)** – A proposed $1 billion program in FY 2013, the NNMI is envisioned as a nationwide network[1] of up to 15 Institutes for Manufacturing Innovation (IMIs) to provide the R&D infrastructure needed to support a robust advanced manufacturing sector by filling a critical gap in the U.S. innovation pipeline. The NNMI will help ensure that manufacturers have access to critical expertise and facilities needed to meet America's advanced manufacturing needs. The Advanced Manufacturing National Program Office (AMNPO) is coordinating the stakeholder outreach for the design of the NNMI, and is positioned to launch the program (upon funding).

    - **Status**: Stakeholder outreach for input to the design of NNMI is ongoing. Legislation is required to establish this program.
    - **"Pilot"** - In August, DOD announced the new National Additive Manufacturing Innovation Institute (NAMII) that was awarded to a consortium based in the northeastern OH – western PA – WV "Tech Belt." At least $30 million in government funding (from DOD, DOE, NASA, NIST, and NSF) will be matched by $39 million from the proposer team ($20 million from industry). Though not officially part of the NNMI program, many lessons learned in designing and building NAMII are strengthening Federal coordination and the design for the NNMI.

- **AMTech** – This proposed NIST program ($21 million in FY 2013) will provide funding to establish industry-led consortia to create technology roadmaps to identify and tackle long-term R&D challenges shared by industry. AMTech consortia will enable university research capabilities to be focused on industry-driven R&D, lower the risk to investment in new technologies, and accelerate technology transfer.

    - **Status**: The AMTech program is supported in both the House (at $21 million) and Senate (at $14.5 million) marks for the FY 2013 budget, but as a new program it is not included in the Continuing Resolution for FY 2013 (which extends FY 2012 activities).

[1] The term "network" is used in its most general sense here, but it is highly likely that the institutes will also be interconnected through high speed communication services (e.g. Internet) to facilitate and mutually reinforce their collective work.

VISITING COMMITTEE ON ADVANCED TECHNOLOGY
National Institute of Standards and Technology

NEW Organizational Resource in the NIST Portfolio:

- **Advanced Manufacturing National Program Office (AMNPO)** – Created in December 2011 by the Secretary of Commerce, the AMNPO is an interagency office hosted by NIST, which serves as the central point of contact for federal programs in advanced manufacturing. The purpose of the AMNPO is to create and implement a whole-of-government advanced manufacturing strategy. The AMNPO is also responsible for planning and executing the NNMI.

NIST FY 2013 Requested Funding in Advanced Manufacturing Programs		
NIST Program	*FY 2013 Requested Budget*	*Additional Comments*
Laboratories	$135 million	This includes new initiatives funded starting in FY 2012: smart manufacturing; biomanufacturing; advanced materials modeling and simulation; and nanomanufacturing.
AMTech	$21 million	VCAT provided support for this program in the 2011 Annual Report; the report noted that the funding level needs to be sufficient for the program to be successful.
MEP	$128 million	Federal funding leveraged over 60 MEP centers; each center provides 2:1 cost share of the program.
NNMI	$1 billion	Mandatory spending – requires legislation.
Baldrige	$0	This program has transitioned to the private sector.

In addition to hearing from NIST on these programs; the VCAT was also briefed by Dr. Kanti Jain who chaired a National Research Council committee that was charged with assessing the NIST manufacturing portfolio. Principal findings in the report included a positive overall assessment of the technical merit and scientific caliber of research. Research teams were found by the panel to be highly qualified and among the best in the world. The panel did, however, find room for improvement in project selection, organization, and metrics. Further, the panel found that interactions with industry should be expanded, including more visits to companies and greater awareness of industry practices. The VCAT agrees with these findings, and sees both the proposed AMTech Program and the NNMI program as efforts that will help strengthen NIST's ties to industry.

OBSERVATIONS:

While manufacturing and standards have been a part of the NIST (and the former National Bureau of Standards) portfolio from its origins, this new program is particularly vital to the future of the American economy. Efficient manufacturing of complex goods lies at the heart of successful export economies and the re-invention of manufacturing and manufacturing jobs in America has to be considered fundamental to future economic growth.

The VCAT fully supports the ongoing and planned work at NIST, and feels strongly that NIST's measurement science mission, its unique and longstanding relationship with industry, and its broad portfolio of programs make it a critical element of the Administration's efforts to strengthen manufacturing in America.

RECOMMENDATIONS:

> The VCAT strongly urges Congress and the Executive branch to fund NIST's Advanced Manufacturing programs at the maximum level feasible. Just as the Agricultural Extension program was the backbone of the American farming economy in the 20th century, the Advanced Manufacturing programs will provide a similar role in the 21st century.

- The VCAT recommends that NIST establish additional definitions and metrics beyond job creation and competitiveness for successful outcomes from the Advanced Manufacturing programs. Metrics might include environmental impacts, lifecycle costs, re-use of materials and subsystems, carbon footprint measurement standards, portable on-line measurement systems, and modularity.
- The VCAT is interested in understanding more fully the interaction between the IMIs and other manufacturing initiatives undertaken by NIST. The potential for mutual reinforcement seems very high and should be a strategic goal of the programs.
- NIST should consider linking Cyber-Physical Systems and Advanced Manufacturing efforts to develop devices and appliances that measure themselves, report status and other usage statistics, security status, etc. The Smart Grid program might be a fruitful area in which to pursue this idea.

4. NIST Role in the Public Safety Network

Following up on last year's work looking at the NIST role in the Wireless Innovation Initiative (http://www.nist.gov/director/vcat/upload/Desirable_Properties_of_a_National_PSN.pdf), the Committee heard updates from both the National Telecommunications and Information Agency (NTIA) and NIST regarding developments surrounding the creation of FirstNet and operations of the NIST Public Safety Communications Research (PSCR) Program. Title VI of the Middle Class Tax Relief and Job Creation Action of 2012, Public Law 112-96, included provisions for the public safety communications and electromagnetic spectrum auctions. This legislation creates the path toward a nationwide public safety broadband network (PSBN). FirstNet was established by the Act as an independent authority within NTIA and is headed by a 15-member Board that takes all actions necessary to ensure the design, construction, deployment, and maintenance operations of the nationwide PSBN in consultation with others, including the NIST Director. The Board is not an advisory committee; however, it will establish a public safety advisory committee.

Congress granted NTIA borrowing authority not to exceed $2 billion to implement the governance of the public safety spectrum and $135 million for the State and Local implementation grants. NTIA will borrow the initial funds from the general fund of the Treasury prior to the deposit of auction proceeds into the Public Safety Trust Fund (PSTF). Once the auctions take place, funds deposited in the PSTF are available on a cascading order of priority as mandated by statute, beginning with the repayment of the amounts borrowed by NTIA. If the auction raises $7.235 billion, then $100 million will be available to NIST to manage for public safety research and development. Further down on the priority list is $200 million for additional public safety research provided the auction raises these funds. The research funds may be available in a few years.

The PSCR Program is a successful joint partnership between NIST's Law Enforcement Standards Office (OLES) and NTIA's Institute for Telecommunications Sciences housed in Boulder, CO. This program includes staff from both organizations that have been operating as a team for about 15 years. Some PSCR activities directly overlap FirstNet's responsibilities within the parameters of the legislation. These responsibilities cover requirements, standards, testing, and research and development (R&D). PSCR has been working in the area of public safety requirements for the safety, security, and resiliency of the network for years, especially in the broadband arena by chairing, leading, and/or participating in working groups and other activities. With regard to standards, PSCR has been working to drive public safety needs into international standards bodies when developing standards for voice, data, and video communications. For example, PSCR has introduced a work item into the 3rd Generation Partnership Project to address Direct Mode communications, an effort that aligns directly with the recent VCAT report on public safety. In the area of testing, PSCR is working to identify the commercial test processes that FirstNet can leverage. Turning to R&D, the PSCR is responsible for the only operational multi-vendor broadband Demonstration Network in the United States, which is now deploying four separate operational cellular networks from different manufacturers. Over 60 manufacturers are involved with the Network through Cooperative

Research and Development Agreements (CRADAs) and about $60 to $70 million of equipment have been donated through CRADAs. Other R&D efforts include audio quality testing, video quality testing, 700 megahertz modeling and simulation, and Land Mobile Radio to Long Term Evolution (LTE) interface.

In addition to the discussions on the PSCR Program, the VCAT was also briefed on the intention of NIST to create a Center for Advanced Communications at its Boulder laboratories that would take advantage of the unique mix of research and testing and evaluation capabilities resident there. The Center would help enhance mission effectiveness by better coordinating the measurement science, testing, and standards functions of NIST and NTIA in the area of advanced communication addressing challenges in a number of areas including, Radio Frequency Technology, digital information processing, and spectrum sharing. Furthermore, the Center would create a single focal point for engaging both industry and other government agencies to meet their testing, validation, and conformity assessment needs. The VCAT is excited by the possibilities of the Center and looks forward to working with NIST over the coming year to help support its development.

OBSERVATIONS:

The VCAT report on public safety communications referenced above drew attention to the hazards of relying heavily on existing infrastructure, such as the mobile communication service industry's Long Term Evolution (LTE) design and its associated network of towers and base stations. The report emphasized the need for peer-to-peer (or "talk around") capability, backward interoperability with P25-based devices and, perhaps most important, the ability to form ad hoc networks using packet switching, delay and disruption tolerant methods and application of the Internet protocols to support carriage of voice, video and data to and from first responders and information facilities available from online public safety resources in government at all levels and the private sector.

RECOMMENDATION:

- NIST should track closely the progress of the NIST efforts in FirstNet to achieve coverage and interoperability at all levels of public safety operation. Interoperability is needed not only among the civilian first response community but also with the military when they are called into service to respond to major disasters.

5. NIST Centers of Excellence

The Centers of Excellence, proposed at $20 million in the President's FY 2013 budget, are an opportunity to leverage NIST base resources through partnerships with academia and industry. NIST has a proven track record of partnerships, including JILA (with the University of Colorado), the Institute for Bioscience and Biotechnology Research (IBBR – with the University of Maryland Biotechnology Institute), the Joint Quantum Institute (JQI – with the University of Maryland and the National Security Agency), and the Hollings Marine Laboratory (with the National Oceanic and Atmospheric Administration, the South Carolina Department of Natural Resources, the College of Charleston, and the Medical University of South Carolina). The goal of the FY 2013 proposed program is to create multidisciplinary centers that complement and extend U.S. measurement science capabilities in critical areas of emerging technologies.

The structure and scope of the centers is currently being developed. NIST is considering a variety of engagement and governance models, ranging from a user facility model (similar to the Center for Nanoscale Science and Technology), to a problem-focused, multi-stakeholder model (similar to the National Cybersecurity Center of Excellence), to long-term collaborations (similar to JILA). Form may follow function; as the governance model may be tailored to suit the nature of the technology and measurement science needs, and therefore, may be different from one center to the next.

NIST is currently gathering input from multiple sources to identify potential investment areas for the centers. Each laboratory has provided a list of candidate research topics, along with proposed governance models and specific measurement science issues. Additionally, the Science and Technology Policy Institute (STPI), part of the Institute for Defense Analysis (IDA) was awarded a contract to independently develop research ideas for centers of excellence. STPI scanned the available literature and interviewed key subject matter experts in order to identify emerging areas of science with significant potential for impact, clear measurement science needs, and alignment with NIST mission and strategic direction. These inputs, along with other factors, will help jump-start the selection process for centers of excellence, which may have to move quickly, depending upon when the funding becomes available.

OBSERVATIONS:

Measurement and analysis lies at the heart of successful forensic work and, increasingly, NIST measurement science can and is playing a key role in the steady improvement in forensic analysis. A Center of Excellence in forensic science could be a potential tool to strengthen this community.

In relation to the topic, the VCAT also received several updates on the National Cybersecurity Center of Excellence (NCCoE). Significant progress has been made in standing up the NCCoE to date, and the VCAT is strongly encouraged to learn that NIST is investigating the possibility of establishing a Federally Funded Research and Development Center (FFRDC) as the managing entity for the NCCoE. The VCAT believes that such a mechanism could greatly enhance the ability of the NCCoE to accelerate the delivery of cybersecurity solutions to industry. The VCAT looks forward to supporting NIST in this area over the coming year.

RECOMMENDATIONS:

- A gap analysis for emerging areas of national need should inform the choice of focus for new centers of excellence.
- The VCAT recommends that NIST should expand its footprint in forensic science.
- In addition to its existing partners that have established JILA, the Institute for Bioscience and Biotechnology Research (IBBR), the Joint Quantum Institute (JQI), and the Hollings Marine Laboratory (HML), NIST should consider formally adding NSF as a partner, especially in relation to cybersecurity and cyber-physical systems.
- While a National Cybersecurity Center of Excellence has been created, the VCAT recommends that its scope be expanded to include "cyber-safety" which includes attention to user behaviors, civilian private sector cyber practices, and coordination with other agencies including the Department of Homeland Security, Department of Justice, and the National Security Agency. The VCAT endorses the FFRDC framework for the management and operation of the NNCoE.
- Reference architectures and metrics of security and safety deserve attention, as does the development of tools for measuring these properties. Compliance with recommendations needs to be leavened with a risk-based approach to conformity assessment practices.

6. R&D Planning

Dr. Willie May, Associate Director for Laboratory Programs (ADLP), reported to VCAT on R&D planning at NIST. As science and technology priorities come from Congress, the Administration, industry, and other federal agencies, NIST planning is a fusion of top-down and bottoms-up planning processes. Planning challenges include the breadth of the NIST mission and the dynamic environment of innovation and technology development. These challenges are managed through several different components of the organization.

The ADLP is primarily responsible for strategic planning over a three to four year horizon for the Strategic Focus Areas, with support from the Program Coordination Office, as well as the laboratory directors. Strategic planning includes both program and budget development. In addition, the ADLP is responsible for overseeing measurement services programs and representing the laboratory programs to industry, academia, and other government agencies.

The laboratory directors are primarily responsible for planning within the mission space of their respective laboratories, with a five to ten year horizon. In addition, the laboratory directors have responsibility for the effective implementation of the programs and projects and delivery of measurement services.

OBSERVATIONS:

The VCAT continues to look for more clarity and depth in strategic planning, recognizing that NIST operates in a dynamic environment in which demands arise from a variety of sources that can and do affect its ability to adapt. The newly instituted planning framework offers the opportunity to align the organizational long term plans around the three key perspectives of National Priorities, Science and Technology Trends, and Internal Processes. This approach can then lead to clearly defined and actionable plans around Programs, Technical Capacity, and Process Improvements.

RECOMMENDATION:

- The VCAT strongly encourages NIST to drive this new strategic planning process as quickly as possible and we look forward to reviewing the progress during the upcoming year.

6a. Next Generation Measurement Services

Measurement services are a core function at NIST. The next generation delivery of measurement services is an example of one of the strategic issues that NIST is examining in order to ensure that its programs and services are well aligned with future needs.

Measurement and calibration services assure the accuracy of millions of measurements made daily in medical clinics, manufacturing plants, industrial facilities, and crime labs throughout the United States. NIST performs over 18,000 calibrations on over 1,800 objects annually. However, traditional measurement service may require significant down time for customer equipment or devices, consume significant NIST staff time, require periodic recalibration, and may be less flexible when customer needs change.

NIST is developing a next-generation plan for advancing measurement services, called NIST on a Chip. NIST on a Chip is an integrated program to develop and deploy NIST-traceable measurements and physical standards that are deployed in the customer's lab, factory floor, device, or system; are easily used and integrated; are rugged, yet small in size and weight; and have low power consumption. As the reference standard is integrated into the device or process, many of the difficulties of the traditional measurement service model can be overcome, including minimal down time and recalibration, as well as improved flexibility for innovation. Measurement technologies include force, fluid flow, pressure, length, voltage, current, magnetic field, time and frequency, optical power, displacement, and electric field.

OBSERVATIONS:

The VCAT was strongly impressed by the potential of the proposed work and looks forward to seeing progress in this area. In particular, device self-measurement and potentially reporting via network raises the possibility of the creation of significant databases of information that could be used to analyze and improve efficiency of electrical power usage and other resource utilization. The Smart Grid program is prototypical of this notion. These ideas are clearly applicable to the advanced manufacturing initiatives in which production plant automation, inventory and raw materials management, product production selection, among other things, are key to efficient and timely production of goods and services.

6b. Three Year Programmatic Plan

The Programmatic Plan is not yet available as it is influenced by the FY 2013 appropriations and FY 2014 proposals from the President. The Committee will review and comment on this plan when it is available and report separately on its findings and recommendations.

7. NIST Budget

NIST Budget (Dollars in Millions)

	FY 2012 Enacted	FY 2013 Request	FY 2013 House Marks	FY 2013 Senate Marks	FY 2014 Request**
STRS	$ 567.0	$ 648.0	$ 621.2	$ 623.0	**
Laboratory Programs	518.0	572.7			**
Corporate Services	18.5	18.5			**
Stds Coord. and Spec. Prgs.	30.5	56.8			**
ITS	$ 128.4	$ 149.0	$ 149.0	$ 143.0	**
Advanced Manu. Tech. Consort.	0.0	21.0	21.0	14.5	**
Hollings Manuf. Ext. Prg.	128.4	128.0	128.0	128.5	**
Technology Innovation Program	0.0	0.0	0.0	0.0	**
Baldrige Perf. Excel. Prog.	0.0	0.0	0.0	0.0	**
CRF	$ 55.4	$ 60.0	$ 60.0	$ 60.0	**
Const. & Major Renovations	13.9	11.8			**
Saf. Cap., Maint., Maj. Repairs	41.5	48.2			**
Total Discretionary	$750.8	$857.0	$830.2	$826.0	**
NNMI (Mandatory)	$0.0	$ 1,000.0	$ -	$ -	**
WIN (Mandatory) *	$0.0	$0.0	$0.0	$0.0	**
Total NIST	$ 750.8	$ 1,857.0	$ 830.2	$ 826.0	**

* The Middle Class Tax Relief and Job Creation Act of 2012 authorized $300 million in funds, of which NIST is anticipating a Congressional Budget Office score of $100 million in FY 2017. The first $100 million is provided to NIST after successful spectrum auction of $7.2 billion or more, and an additional $200 million will be allocated if spectrum auctions net more than $27.6 billion (could take up to 7 years).

** The FY 2014 Request is unavailable at the time of writing this report

7a. FY 2013 Appropriations

As stated in the VCAT's 2011 Report, the VCAT is strongly supportive of the President's request for NIST in FY 2013, and looks forward to an appropriation that will continue to support the priorities articulated, especially in the area of manufacturing and advanced communications. The VCAT agrees strongly with the focus on manufacturing and is supportive of the requested increases to the NIST laboratory programs, and believe that they will both increase capabilities at NIST, and create improved partnership opportunities with industry and academia, enabling NIST to interact more effectively across the innovation ecosystem.

A major element of the FY 2013 request was the $1 billion to stand up the National Network for Manufacturing Innovation (NNMI). Over the past year, NIST, through the Advanced Manufacturing National Program Office has engaged in significant national outreach to scope the program. The network is envisioned to bridge an existing gap in the U.S. innovation ecosystem that exists between basic research and deployment of commercial products and technologies. The entire network will strengthen efforts in a number of critical focus areas determined by the selection of IMIs that complement one another and build on regional strengths. As a partnership-driven endeavor requiring co-investment (i.e. by institute partners from industry, economic development organizations, associations and educational institutions), an IMI may have a focus on such topics as a manufacturing process, an advanced material, an enabling technology, or an industry sector. Each IMI will initiate major activities, which could include:

- Applied research and demonstration projects (for example, for reducing cost/risk on commercializing new technologies, or solving pre-competitive industry research challenges);
- Technology integration through development of innovative methodologies and practices for supply chain integration;
- Engagement with small and medium-sized manufacturing enterprises; and
- Education, technical skills, and workforce development at all levels.

The VCAT believes that this program will fill an important void in the U.S. infrastructure that is supporting manufacturing, and hopes to see continued support for this effort.

The VCAT is supportive of the proposed $128 million for the Manufacturing Extension Partnership (MEP) and the requested $21 million for AMTech. While $21 million will be sufficient to launch the program, as previously stated, the VCAT strongly recommends that the AMTech program be funded at a level that would enable it to have maximal impact.

Over this past year, the VCAT also had the opportunity to visit the NIST facilities in Boulder, and can reaffirm the importance of maintaining funding for the ongoing renovation projects, as any major stoppages or delays will leave research projects in less than optimal temporary facilities, and would likely lead to significant cost increases to the project as a whole. The VCAT remains concerned that the $48.2 million proposed for NIST's routine maintenance and repair budget is not sufficient to effectively maintain NIST's laboratory facilities, especially given the aging nature of the General Purpose Laboratories and the significant increases in new facilities through the American Recovery and Reinvestment Act (ARRA) construction. The inability for NIST to effectively address major repair needs could negatively impact the safe and efficient operations of NIST.

<u>OBSERVATIONS:</u>

Because of the uncertainty in the budget process for FY 2013 and FY 2014, the continuing resolution, and the potential for sequestration, the VCAT has not reviewed further the budget for FY 2013 and proposals for FY 2014. Once clarity is available regarding the current year budget and the President's proposal for FY 2014, the VCAT will review and make observations and recommendations as appropriate and report these results in an addendum to this annual report.

SUBMITTED BY DR. WILLIE E. MAY, ASSOCIATE DIRECTOR FOR LABORATORY PROGRAMS, NIST

Material Measurement Laboratory:

An Overview of Our Programs in Biology, Chemistry and Materials Science

May 2011

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

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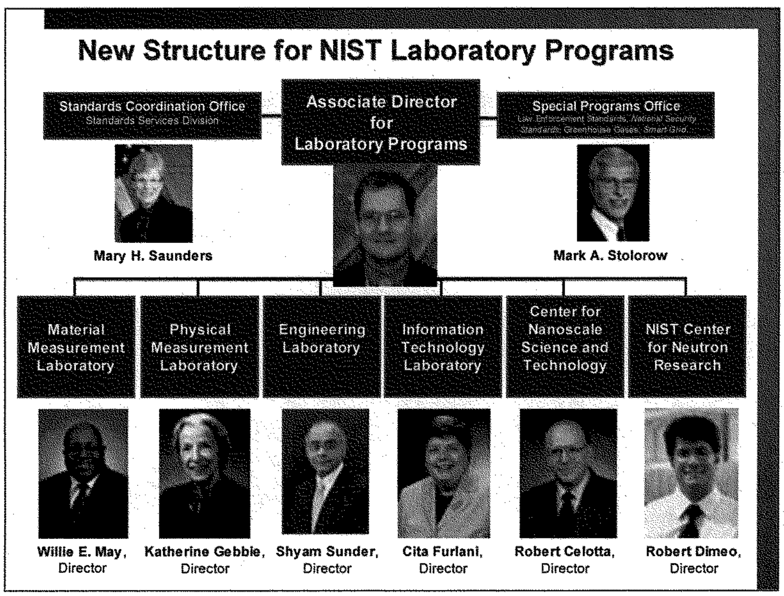
Material Measurement Laboratory
Overview of Programs

Background

Effective October 1, 2010, after 20 years with its research programs aligned largely by scientific disciplines, NIST reorganized its laboratory functions according to a mission-based structure consisting of four mission-based Laboratories and two National User Facilities as shown below:

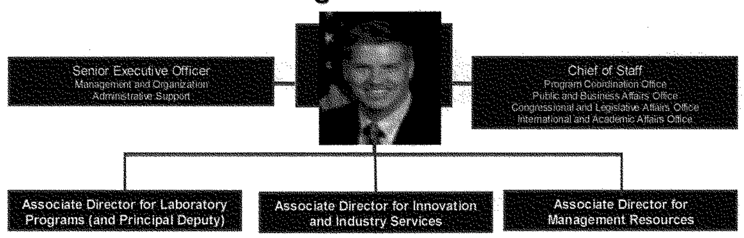


It was felt that such a structure will allow more day-to-day operational decisions to be made by the major organizational units, will improve interdisciplinary research by making it easier to form research groups with the needed expertise, and will provide greater accountability by ensuring that organizational units are responsible for all major products and services that meet NIST's mission authorities from the research to develop them to the delivery of those products and services to customers.

Earlier, in the Spring of 2010, the decision was made to eliminate the NIST Deputy Position and establish three Associate Director Positions as shown below:

Material Measurement Laboratory
Overview of Programs

New NIST Organizational Structure



Improves the efficiency and effectiveness of NIST in realizing its mission by:

- strengthening and stabilizing the Director's Office by establishing a core, senior career leadership team
- better integration of research and measurement service activities
- facilitating a stronger client-service model between the Management Resource Functions at NIST and the Laboratory and Technology programs

In the new structure, the **Material Measurement Laboratory** has the responsibility for serving as the national reference laboratory for measurements in the chemical, biological, and materials sciences through activities ranging from fundamental research in the composition, structure, and properties of industrial, biological and environmental materials and processes to the development and dissemination of certified reference materials, critically evaluated data, and other programs to assure measurement quality. Additionally, MML is responsible for coordinating the NIST-wide Standard Reference Materials and Standard Reference Data Programs.

The Physical Measurement Laboratory is charged with realization and dissemination of the national standards for length, mass, time and frequency, electricity, temperature, force, acceleration, pressure and vacuum, flow, acoustical pressure, and microwave, optical and ionizing radiation by activities ranging from fundamental research in measurement science to provision of measurement services and standards. PML is also responsible for coordinating the NIST-wide Weights and Measures, Laboratory Accreditation, and Calibration Service Programs.

The Engineering Laboratory develops and disseminates advanced manufacturing and construction technologies, guidelines, and services to the U.S. manufacturing and construction industries through activities including measurement science research, performance metrics, tools for engineering applications, and promotion of standards adoption. EL has NIST-wide responsibility for Fire research, the National Earthquake Hazard Reduction Program, National Windstorm Impact Reduction Program, National Construction Safety Team, Collaborative Manufacturing Research Pilot Program, and Manufacturing Fellowship Program.

The Information Technology Laboratory develops and disseminates standards, measurements, and testing for interoperability, security, usability, and reliability of information systems, including cybersecurity standards and guidelines for Federal agencies and U.S. industry, through fundamental and applied research in computer science, mathematics and statistics. ITL also has NIST-wide responsibility for supporting the Federal Information Security Management, the Health Information Technology and the Help America Vote Act.

The **NIST Center for Neutron Research** is charged with safely and reliably operating a national user facility providing neutron-based measurement capabilities to U.S. researchers from industry, academia, NIST, and other government agencies in support of materials research, nondestructive evaluation, neutron imaging, chemical analysis, neutron standards, dosimetry, and radiation metrology.

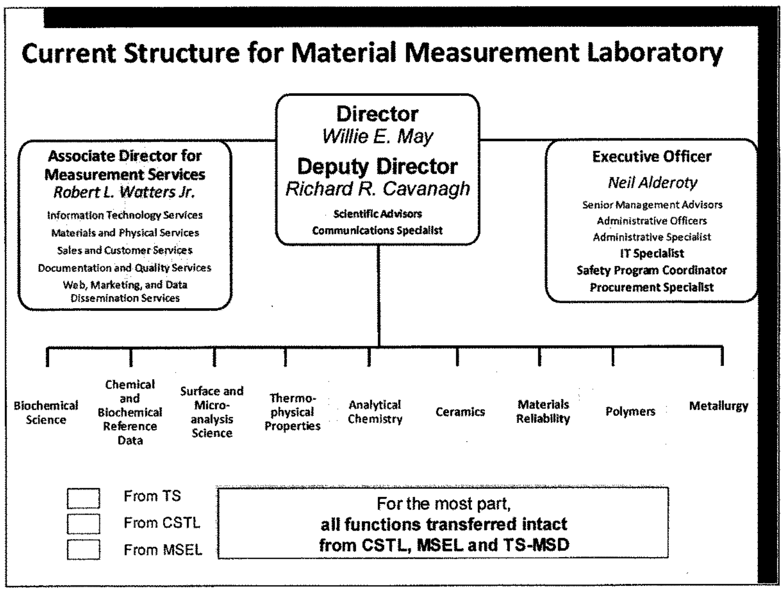
The **Center for Nanoscale Science and Technology** is charged with safely and reliably operating a national, shared-use facility for nanoscale fabrication and measurement to develop innovative nanoscale measurement and fabrication capabilities and to support researchers from industry, academia, NIST, and other government agencies in nanoscale technology from discovery to production.

Structure of the Material Measurement Laboratory

One of the principal outcomes of the restructuring of the NIST laboratory programs has been the union of several divisions within the Engineering, Material Measurement, and Physical Measurement Laboratories. The Information Technology Laboratory and the User Facilities were basically unchanged in terms of composition. In a second step, each of these OUs was charged with the responsibility to evaluate its technical activities and programs and realign its structure to achieve:

- Optimization of the alignment of organizational structure with major activities/program areas
- Full integration of operational responsibility into the programs; and
- Maximization of the efficiency and effectiveness of the organization

As shown below, MML comprises former Chemical Science and Technology Laboratory, Material Science and Engineering Laboratory, and the Measurement Service Division from the Technology Services organization.



Planning for the Future

During the early part of FY2011 (October-November, 2010) several models were explored for realignment of the structure of MML:

- Status Quo with minor tweaks
- Discipline-based (with crosscutting program management structure)
  - *i.e., chem, bio, materials science, data and informatics, etc.*
- Competency-based (with crosscutting program management structure)
  - *i.e., Composition Measurements, Property Measurements, Structural Determination, Data and Informatics, etc.*
- Sector-based
  - *i.e., energy, environment, climate science, healthcare, automotive, forensics and homeland security, food safety and nutrition, etc.*

However, after some thought, we decided to step back a bit from our rush to realign MML's structure and focus our energies on establishing a vision for MML's chemical, biology and materials science activities. As a first step, we assessed the scope and magnitude of the current programs within the new MML organization. This information is provide in a series of tables that follow in an Appendix, looking at our budget in terms of existing Divisions and Programs, and in terms sub-mission area (chem., bio, material science and the sectors that they serve). In addition, three teams were established to look more closely at the three areas in terms of existing activities, and what the future is likely to hold in those three areas where NIST is likely to be expected to provide support. Specifically, the teams were to consider three major components in developing a vision for the sub-mission area: (1) an environmental scan to assess the state of the sub-mission space in the world now and focus areas for the future; (2) the current state of MML's sub-mission space, and (3) the future state of MML's materials science activities. The following three sections summarize those analyses, and once validated, the vision established would drive everything we do including, but not limited to, our organizational structure, investment priorities and staffing decisions.

Biological Measurement Science and Standards

Biological Measurement Science and Standards

Advancing the measurement and computational sciences of biological systems will be a decisive factor in fulfilling the promise of the biosciences to greatly enhance our economic security and quality of life. Biological systems are the foundation of all life on earth. The science of understanding how these systems operate and interact with one another (the biosciences) is increasingly important. As our population grows, we will need more efficient and sustainable ways to grow food, keep people healthy, produce energy, and manufacture biological drugs, therapeutics, and chemicals. These advances can only be realized by gaining a deeper understanding of how biological systems operate.

The bioscience industry is expansive and is a major driver of future U.S. economic growth with significant impact in multiple economic sectors, including healthcare, energy, agriculture, security, and manufacturing. Built around the recombinant DNA technologies discovered in the 1970s, this sector in the U.S. has exploded. Today there are over 1,400 biotechnology companies, of which more than 300 are publicly traded and have a combined market capitalization value of $410 billion dollars. In addition, all major pharmaceutical companies, who have traditionally developed small-molecule drugs, are increasingly focusing major resources on developing biotechnology-based large-protein therapeutics.

With a reputation as the Nation's problem solver and final authority on measurements and standards, NIST plays a leading role in accelerating innovations in the biosciences. The Material Measurement Laboratory (MML) leads this role and develops and disseminates reference standards (reference methods, certified and standard reference materials and data) to support the accuracy of those measurements, which are used to make critical decisions in health care, research and the pharmaceutical industry. The laboratory also maintains robust programs to develop standards for numerous areas of laboratory medicine and molecular pathology including genetic testing, DNA sequencing, clinical proteomics, toxicology, immunology, and tests for serum protein disease markers such as prostate-specific antigen. MML's provision of state-of-the-art measurement science, standards, and technology assures the accuracy and comparability of biological measurements and stimulates development of new measurement technologies.

I. External Environmental Scan for Biological Measurement Science and Standards

To identify and assess the measurement and standards needs of the nation, several sources of information in the industry areas that depend critically on biological measurements and standards were surveyed. These information sources include: clear program directives from the federal government, e.g. OSTP memoranda and congressional bills; stakeholder workshops; national and international meetings and conferences; and direct engagement with outside public and private organizations. Additionally, a number of roadmap and workshop reports covering different aspects of biological measurements and standards were reviewed and discussed to inform the strategic visioning conclusions. A recent example is the report from a 2008 NIST workshop, "Accelerating Innovation in 21st Century Biosciences: Identifying the Measurement, Standards, and Technological Challenges" which developed a broad assessment of the state of biological measurement science and standards[1]. Other specific sources include documents from the National Academy of Sciences[2, 3], National Science and Technology Council[4], Office of Science and Technology Policy[5], World Technology Evaluation Center, Inc.[6], previous NIST stakeholder workshops[7], and other community-driven roadmapping exercises [8, 9, 10, 11].

Broadly stated, the field of bioscience can be considered as the science of understanding how biological systems operate and interact with one another. The knowledge generated by this field can be used for applications ranging from the curing of human disease to production of energy. The enterprise of bioscience is founded on measurements of individual biological molecules and biological systems, or their response to perturbations (environment, synthetic materials, devices, etc.).

II. Current State of Biological Measurement Science and Standards Activities in MML

II.a. Scope

The MML's leading role in the biosciences is to develop, provide and advance the necessary measurement infrastructure – methods, reference materials, reference data, technologies and models – to enable accurate, comparable, and reliable measurement of biological molecules (nucleic acids, proteins, metabolites, etc.), systems (viruses, bacteria, cells and tissues), materials (therapeutics, drug delivery platforms, and biomaterials), and devices designed to interact with biological systems. Measured properties include:

- Molecular structure,
- Chemical composition,
- Amounts of substances
- Concentration in matrices,
- Biological function and biological response (phenotype),
- Biological activity, and
- Intermolecular interactions in biological systems

In addition, MML supports fundamental research in biological measurement science to address and serve current and projected measurement needs of this rapidly expanding field.

II.b. Fiscal Profile

In FY11, MML had a total appropriation of ~$100M, with one-fifth of the total appropriation, $20M, targeted specifically to biological measurement science and standards activities (defined as the total STRS bioscience allocation). Of the total STRS bioscience allocation, ~85-90% was targeted to the biomedical and health industries, while the remaining supported four other sectors: Security, Safety and Forensics; Energy; Environment and Climate; and Advanced Materials. Additionally, significant other agency support, ~$5M, was used to serve the measurement needs of the bioscience community in areas of forensics, biosecurity and healthcare. Other agency funding was obtained primarily from the Department of Homeland Security, the Department of Justice, and the Department of Health and Human Services. In addition to MML appropriated funds and other agency funds, ~$2.7 M was obtained from the NIST working capital fund to develop and produce SRMs for the biosciences community (combined Standard Reference Material (SRM) and Standards Development (SD) funds). For example, MML maintains reference materials for over 30 analytes measured by chemistry-based clinical tests.

II.c. Current Activities in Support of Customer Needs
The biological measurement science and standards activities within MML and NIST have grown in the past five years through both increased investment of existing MML resources into biologic drug manufacturing and genomic sequencing, as well as a result of budget initiatives targeted toward bioimaging, laboratory medicine (genetic testing, molecular pathology and individual blood protein biomarker analysis). Additionally, there have been budget increases in areas that benefit from biological measurement science such as environmental, health, and safety issues of nanotechnology. While these areas have experienced targeted growth, the current portfolio for MML is much broader and has been developed from continuous assessment of customer needs, which we highlight below.

NIST customers in the biological measurement science area are from the federal government, industry and academia. The greatest demands come from the industrial community that provides medical and diagnostic equipment and tests where the impacts of biological measurements play out in life and death decisions that are made every day by physicians. Additionally, representatives from several other large industrial sectors including energy, environment, agriculture, and biopharmaceutical/biomanufacturing expressed critical needs for biological measurement science, standards, and infrastructure to support their current and next generation of products and services. As stated previously, the needs from these sectors were gathered, organized and compiled into a NIST Special Publication[1].

The Department of Commerce publishes annually a U.S. Industry Exporters' List. From this list, the industry sectors that are most profoundly impacted by bioscience measurements are the following: (1) Agriculture; (2) Environmental and Energy; (3) Food/Food Processing; (4) Medical/Scientific Products and Equipment; and (5) Safety and Security. The current needs from these sectors and their associated industries that fall under the purview of the NIST mission are described briefly below. In the process of developing the list of current needs, NIST activities were mapped onto each of the sectors. Some examples of current NIST activities are provided as 'NIST examples'. This section is meant to be a survey of all of the areas in biomeasurements that customers perform and examples of what could be done, i.e., in some cases we carry a heavy work load and in others we are not. For the most complete picture of what MML is doing know is provided in fiscal profile (Section II.b).

Agriculture Sector
Animal and crop improvement – Standards, methods, and technologies to support measurements for animal breeding, or monitoring natural or genetically engineered

terrestrial food sources. NIST example: Methods for detecting genetically modified organisms in food using genetic markers

Aquaculture – Standards and methods to support measurements related to the farming of fresh water and marine aquatic organisms for food production. NIST example: Methods to study virus affecting salmon populations in aquaculture

Environmental and Energy Sector

Event monitoring and bioremediation – Standards, data, and methods to support measurements made for the analysis of toxins/pollutants acutely or chronically released into ecosystems; and methods used for removing them. NIST example: Reference materials for accurate assessment of exposure to toxic elements and anions.

Monitoring ecosystem health and safety – Standards, data, and methods to support measurements made for the analysis of adverse affects of environmental insults (chemical, nanoparticle, climate change) on ecosystems. NIST examples: environmental biomarker measurements, and toxin quantitation.

Toxicology – Standards, data, and methods in support of measurements on living organisms to discover toxicological mechanisms or perform health assessments on potential environmental toxins. NIST example: measuring biological damage caused by environmental agents

Nano EHS - Standards, data, and methods needed to assess the physical properties of nanoparticles to underpin environmental, health, and safety (EHS) studies of nanomaterials, particularly mechanisms of biological interaction with nanomaterials. NIST example: Gold nanoparticle reference materials.

Bioenergy – Standards, data, and methods in support of measurements for discovery, development, manufacturing, and deployment of combustible fuels produced by or extracted from biological organisms. NIST example: Standard reference database for thermophysical properties of biofuels.

Food / Food Processing Sector

Food safety and quality – Standards, data and methods to support measurements to insure quality and safety of products consumed for largely nutritional purposes including methods for infectious disease and allergen testing. NIST example: Reference standards and procotols for high throughput sequencing for rapid detection of bacterial contaminants in food.

Genetic surveillance – Standards, data and methods to support measurements conducted to determine the genetic identity or the presence of a genetic marker or trait in food seeds, IVF materials or whole organisms. NIST example: methods to measure genetic markers associated with genetically modified organisms.

Medical / Scientific Products and Equipment Sector

Diagnostics

- **Laboratory medicine test discovery, development, manufacturing and use** – Standards, data and methods to support measurements used to discover, detect, quantitate or identify biochemicals, proteins, bacteria, viruses, or cells in humans for diagnostic, predictive or prognostic purposes (blood chemistry, urinalysis, immunodiagnostics, biological activity assays, cell counting/identification). NIST example: Reference methods and materials to support accuracy of cholesterol measurement in serum
- **Imaging diagnostics** – Standards, data, and methods to support measurements made for discovery, development or manufacturing of imaging of gross anatomical structures (photography, CT, MRI, x-ray, ultrasound, nuclear medicine, mammography, etc); includes discovery, development and use of contrast or image enhancement reagents. NIST example: phantoms for medical imaging to enable comparisons of image states at different times and on different instruments
- **Molecular pathology** – Standards, data and methods to support biomarker discovery, and disease identification, staging, prognostication. NIST example: Huntington's disease DNA SRM
- **Physical measurements** – Calibrations and new technologies that support measurement of blood pressure, blood gases, respiratory gas measurements, and other physical measurements of biological systems. Example: temperature calibrations for PCR reactions, vaccine stabilization, etc. NIST example: Pulse oximetry standards.

Drug/Pharmaceutical – Measurements, standards, data, and methods to support the research, discovery, development, manufacturing, and regulatory approval of small molecule and biologic drugs such as protein, nucleic acid and vaccines. NIST example: Protein particulate standards to accurately quantify aggregates in biologics.

Non drug therapeutics

- **Tissue engineering** - Standards, data, and methods to support measurements used to characterize cells and biomaterials for use as tissue engineering/regenerative medicine therapeutics. NIST example: 3D tissue scaffold reference materials.
- **Dental materials**– Standards, data, and methods to support measurements used to characterize, develop, or manufacture dental restorative materials with improved clinical performance. NIST example: redesigned tensometer for more sensitive measurement of stress development in dental materials.
- **Cell-based therapeutics** – Standards, data, and methods to support measurements used to characterize cells for use as therapeutics. Example: live cell microscopy of cell phenotype. NIST example: molecular tools to verify cell phenotype.
- **Gene therapies** – Standards, data, and new methods to support measurements used to determine the safety and effectiveness of genes and genetic materials for therapeutic purposes. NIST example: Standards to support sequence verification for gene therapy constructs for clinical use
- **Vaccines** – Standards for use in the development, manufacturing and delivery of prophylactic and therapeutic vaccines – these are orally- or parenterally-delivered

preparations designed to induce or alter an immune response. NIST example: Calibrations of thermometers used in refrigerators to store labile vaccine preparations (H1N1 flu).

Medical devices (non-diagnostic) – Measurement science, standards, data, and methods to support the research, development, and manufacturing of medical devices for diagnosis, therapy, or surgery. NIST example: Standards for particle flow through surgical masks

Life sciences research – Standards, data, methods, and technologies to support measurements used to discover, develop, manufacture and maintain reagents and instrumentation that can be used for a wide variety of applications across the biosciences. NIST example: Microfluidic platforms for single cell analysis

Bioinformatics – Tools for processing of data derived from experiments on biological systems; developing tools for storage, annotation, dissemination and analysis of this data; combining data acquired from analytical devices with available relevant information, with the objective of deriving meaningful results of direct value to customers. NIST example: "Performance Metrics for Liquid Chromatography-Tandem Mass Spectrometry Systems in Proteomics Analyses" and "Peptide Fragmentation Library" (http://peptide.nist.gov)

Biomanufacturing and bioengineering - Standards, data and methods to support the research, development, and manufacturing of industrial non-medical biochemical products by synthetic methods, cell based systems, or purification from natural sources. NIST example: Higher order structure analysis of therapeutic biologic proteins – post-translational modifications and 3-D structure

Safety and Security Sector

Human identification / molecular biometrics – Standards, data and methods to support measurements made on biomolecules for determining the identity of people for routine identification and for forensics. NIST example: Human DNA Quantitation Standard

CBRNE threat detection – Standards, data and methods to support measurements performed on biomolecules or biosystems for detection, identification, remediation or impact assessment of chemicals, bioorganisms, toxins, radiologic, nuclear or other environments threats purposely delivered. NIST example: Documentary standards for sample collection in case of biothreat.

Biothreat agent remediation – Standards, data and new methods to support measurements for discovery and development of non-pharmaceutical disinfectants for control of infectious agents, both naturally occurring and terrorism related. NIST example: Methods to reduce biofilm formation in contaminated water systems.

II.d. Skill Sets, Expertise, and Capabilities

NIST possesses expertise in the biosciences as well as expertise in several other disciplines including chemistry, materials science, physics, computer science, and mathematics that also support our efforts in biological measurement science. NIST also has significant unique expertise in reference materials, reference data, calibrations, and documentary standards. These core areas of expertise, along with our considerable measurement capabilities and advanced facilities, allow NIST to address critical needs of our customers and the Nation in the bioscience area. In addition, MML's knowledge of the current and emerging technologies that are important to the biosciences enable MML to serve its customers even more so.

Our core capabilities and expertise in the biological sciences can be organized into biological measurement targets that are either molecular in nature (e.g. proteins) or complex systems (e.g. cells) as shown in Table 1. Informatics is cross-cutting to all of the measurement targets.

Table 1. Core Capabilities and Expertise Aligned with Biological Measurement Targets

	Measurement Targets	Core Capabilites and Expertise
MOLECULAR	**Biological and Bioactive Small Molecules**	Identity, composition, concentration, biological activity of metabolites, sugars, lipids
	Proteins	Protein identity, structure, dynamics, function, interactions, concentration; and database tools to support
	Nucleic Acids	Gene and genome-scale sequence analysis (DNA and RNA); DNA and RNA amount (microbial and mammalian); measurement assurance for DNA and RNA; DNA and RNA structure, dynamics and interactions; DNA damage and repair; DNA lesions
SYSTEMS	**Molecular Complexes**	Structure, dynamics and interactions between biological and bioactive molecules including proteins and nucleic acids
	Cells	Metabolic and molecular phenotype and complex responses of mammalian and microbial cells and populations; and database tools to support
	Biomaterials	Materials structure, dynamics, and properties that directly affect their interactions with biological systems (cells and tissues)

II.e. Facilities and Equipment

State-of-the-art facilities and equipment are essential to the capabilities of NIST to develop and deliver precision, validated bioscience measurement tools, reference materials, data, and advanced technologies. NIST currently has facilities and equipment to perform bioscience measurementsof biological and bioactive small molecules, proteins, nucleic acids, molecular complexes, cells, tissues, and biomaterials. These include instrumentation and capabilities for sequence, structure, composition and activity analysis of biomolecules; cellular and tissue imaging and dynamic response; nanofabrication and microfluidic engineering; and computational resources for modeling, data analysis and archiving. NIST is also equipped with specialized facilities for specimen banking, cell culturing and fermentation, as well as certified laboratories for BSL-2 level work.

NIST's two user facilities in neutron science (NCNR) and nanofabrication (CNST) also have capabilities and instruments to support bioscience measurements. A summary outline of the specialized facilities and equipment for bioscience measurements is provided in Table 2.

Table 2. Specialized equipment and facilities and core capabilities they support

Specialized Facilities and Equipment	Supported Core Capabilities
Atomic force microscope	Biologic and bioactive molecules identity and structure; cellular and biomaterials composition (2-D and 3-D mapping) and structure
Mass Spectrometry and Specialized Data Analysis Software for Proteins, Peptides and Metabolites: Ion Trap/Orbitrap Hybrids; MALDI-TOF; Q-TOF; GC/MS; GC/tandem MS; LC/MS; LC/Tandem MS; Quadruple GC/MS; GC/MS-MS and Magnetic Sector GC/MS; Triple Quad. ES-LC/MS; and Linear Ion Trap ES LC/MS-MS; QTOF ES-LC/MS-MS; GCxGC TOF-MS)	Biologic and bioactive molecules, protein, and nucleic acid identity and composition
NMR Spectrometers (300 MHz wide bore solid-state NMR; 600 MHz NMR with multinuclear broadband probe; 600 MHz NMR (Boulder) with multinuclear broadband cryoprobe, Diffusion and HR-MAS probe accessories	Biologic and bioactive molecules, protein, and nucleic acid identity, composition, and molecular interactions
FTIR, Near IR laser, Raman & broadband frequency systems; Broadband CARS microscope	Biologic and bioactive molecules, protein, and nucleic acid identity, composition, structure, and molecular interactions; cellular and biomaterials composition
Hollings NMR Facility (HML): 700 MHz and 800 MHz NMRs with LC/MS/NMR accessory and HR-MAS probe); Keck Center for Biomolecular NMR (IBBR): 900 MHz, 600 MHz, and 500 MHz NMRs with cryoprobe accessories; Super-resolution chemical imaging and laser scanning confocal microscope, optical coherence tomography microscope	Biologic and bioactive molecules, protein, and nucleic acid identity, composition, and molecular interactions
X-ray photoelectron spectrometer X-ray fluorescence facility	Biomaterials composition Cellular and biomaterials composition
Bio-specimen bank (HML) - cryostorage, cryogenic grinding/sample preparation and large-scale freeze drying	Cell and tissue preservation

Biological Measurement Science and Standards

Specialized Facilities and Equipment	Supported Core Capabilities
Atom probe, Dynamic SIMS; Electron microscopes (Titan)	Cellular and biomaterials composition (2-D and 3-D mapping), structure
Flow Cytometry Instrumentation; Live cell imaging facility with fluorescence microscopes equipped with incubation chambers with temperature and atmosphere controls; BSL-2 laboratories for cell and bacterial culture, assays	Cellular metabolic and molecular phenotype
SPR facility for imaging dynamic interactions between cells and extracellular matrix and studying protein-protein interactions	Cellular metabolic and molecular phenotype; biologic and bioactive molecules, protein and nucleic acid molecular interactions
3D Tissue scaffold fabrication and testing	Cellular metabolic and molecular phenotype; biomaterials structure, properties, and composition
CNST - Nanofabrication; Microfluidic device manufacture facility	Devices to support: Biologic and bioactive molecules, protein, and nucleic acid, and cellular identity, composition, structure, and molecular interactions
Computational Chemistry Facilities at NIST	Models to support: Biologic and bioactive molecules, protein, and nucleic acid, and cellular identity, composition, structure, and molecular interactions
BioMark Digital PCR Instrument (Fluidigm); SOLiD "Next Gen" Sequencer (Applied Biosystems); DNA analysis facility for human/plant/clinical identification with genetic analyzers for DNA sequencing and genotyping, plus QPCR and QRT-PCR instruments	Nucleic acid sequence
Nanocalorimeter/calorimeters (DSC, ITSC) Biomolecular Labeling Facility (IBBR) - biofermentation, biochemical/ chemical synthesis, stable isotope labeling of proteins and other biomolecules	Protein and nucleic acid composition and structure Protein and nucleic acid structure and molecular interactions
Small-angle and Ultra-small angle X-ray Scattering	Protein and nucleic acid structure and molecular interactions; biomaterials structure

Specialized Facilities and Equipment	Supported Core Capabilities
NCNR - small angle neutron scattering (SANS, Reflectometry, inelastic neutron scattering, and diffraction)	Protein and nucleic acid structure, dynamics, and molecular interactions; biomaterials structure
Keck Center for Macromolecular Crystallography (IBBR): two X-ray rotating anode X-ray generators and three detectors	Protein and nucleic structure and molecular interactions
Circular Dichroism Spectrometer	Protein structure
Asymmetric Field Flow Fractionation/Multi-angle Laser Light Scattering Instrument; Dynamic microscopy and light obscuration particle counters; analytical ultracentrifuge	Protein, nucleic acid, and cellular structure and molecular interactions

III. Future State of Biological Measurement Science and Standards Activities in MML

III.a. Customers – Measurements, Standards, and Data Projected Future Needs

In Section II.c the measurements, standards, and data needs of the industrial sectors that are currently most affected by bioscience measurements were described. Following extensive intelligence gathering from and dialogue with this community, the following areas described below are most likely to require MML expertise in order to advance new biotechnology products and services at the rate required to move the field forward. The anticipated future measurement needs in these sectors/associated industries are described.

Agriculture Sector and Food / Food Processing Sector

As the world population increases and land becomes scarcer, there will be constantly increasing pressure on agriculture and aquaculture to find creative ways to provide affordable, safe and nutritious foods. The future challenge in this sector will be to meet the rising demands of the world's population by improving the way we grow, produce and protect our agricultural products. Increasing crop yield, monitoring yield and quality, monitoring environmental components that impact growth (microbial species in soil, algal blooms in the sea), developing methods to improve and monitor the use of key resources, and promoting sustainable agriculture will all be critical to securing a future where these demands are met. As a result, the field will require the development of new analytical tools and technologies that are not currently available for effectively and accurately measuring chemical and biochemical composition of plants, animals, soils, and water. As these new biological measurement methods and technologies (genomics, proteomics, metabolomics etc) are used in the development and management of better crops, advanced computational tools will be also be required to deal with the complexity of data analysis, management, representation and visualization. To respond to these needs, NIST should be prepared to support the emerging "-omics" measurement platforms by developing: (1) appropriate reference materials and reference methods to support highly multiplexed assays of proteins, nucleic acids, small molecule analytes; and

(2) new bioinformatics/biocomputing tools to collect, analyze and interpret the results of these assays to support the agriculture sector.

Environmental and Energy Sector

Energy

In the future, there will continue to be an emphasis on obtaining energy from biological sources such as new technologies for the production of alternative biofuels from biological feedstocks through the breakdown of cellulosic material. Two critical needs that will likely grow are: (1) new standard reference data and reference materials for bioenergy process design, optimization, and policy to ensure customer acceptance, comparability of products, and quality assurance; and (2) new measurements for the mechanisms of the breakdown of cellulosic feedstock materials to enable innovations and improvements on the interactions of enzymes with cellulosic materials.

Environment

In the future, stewardship over the environment will require measurements and systems to monitor and track changes in environmental factors such as quantitative levels of toxins, pathogens, biodiversity, or pollutants; genetic profiles of pathogens and microbes; and human exposures and health effects. There are several measurement issues that need to be addressed including: (1) validated biomarkers to provide robust tools to diagnose the environment (e.g. genomics, proteomics, metabolomics of sensitive species); (2) rapid, high throughput assays and diagnostics tools for enhanced bioremediation strategies and preventive technologies; and (3) tools to enable greater interoperability of data sets, bioinformatics, and systems level integration. Together, the field will be able to move beyond simple live/dead tests and towards a deeper mechanistic perspective of systems as complex as the environment.

Medical / Scientific Products and Equipment Sector

Laboratory medicine

Related to the diagnostics industry, it is anticipated that there will be significant growth in the measurement needs of the laboratory medicine and molecular pathology communities. With respect to laboratory medicine, the U.S. clinical diagnostic testing market is estimated to be $45B provided by ~5200 medical laboratories (commercial clinical, hospital-affiliated, and physician-office laboratories) that report results from over 700 routinely-performed tests to physicians. Strategically, NIST must balance its portfolio against the need to support these current tests (which are often of minimal clinical utility when used in isolation) or focus on developing the underpinning measurement science required for industry to make the leap to multiplex testing for acquisition and analysis of disease signatures. Disease signatures are already showing great promise for diagnosing and managing patients with chronic diseases.

With respect to the molecular pathology industry, tests to determine the identity, quantity and location of proteins and nucleic acid sequences in diseased cells are becoming increasingly powerful and actionable tools in medicine. Physicians use molecular pathology results to make rapid and personalized treatment decisions based on data from excised tumors expressing certain tumor biomarkers. False negative and false positive results have profound effects on patient outcomes when the wrong drug decision is made based upon these results. Molecular pathology biomarker standards are strategically important opportunities for NIST because the work we would perform to improve the testing would have profound and direct effects on patient outcomes.

Biologic therapeutics and vaccines
Biologic protein therapeutics and vaccines are increasingly used to treat or prevent many life threatening diseases and represent the primary driver for growth of the pharmaceutical industry. These products currently represent 30% of all drug pipeline research and it is estimated that 50 out of the top 100 drugs will be biopharmaceuticals by 2014. Biologic drugs are currently dominated by protein therapeutics, but substantial growth is also anticipated for vaccines, peptides, nucleic acids, and various combination products. Common to all these therapeutics is their structural complexity and the inability of the current state of measurement science to rigorously define these products. Measurement gaps remain in determining three-dimensional structure, post-translational modifications, and aggregation, all important factors that influence drug efficacy and safety. Measurement barriers also contribute to high product development and manufacturing costs, poor understanding of process and product variability, and the inability to develop lower cost generic versions known as biosimilars. NIST can play an important role in this area by developing the measurement science, reference data, and standards to support manufacturing and regulatory approval of biologic drugs. NIST is working closely with industry, the FDA, academia, and other standards organizations to identify high priority measurement needs and to develop relevant, strategically focused metrology programs for maximal impact.

Regenerative medicine
There remain intense needs in the development of methods, materials, and strategies for regenerative medicine and tissue engineering, including cell-base therapies. In the future, it has been recognized (MATES roadmap) that progress will require 1) measurements and investigation of the cell/material interactions in three-dimensional space rather than traditional cell culture plates; 2) tools able to provide enhanced information about cell differentiation pathways and mechanisms; 3) advanced imaging methods, including the identification and validation of biomarkers and assays, to assess the quality of cell response over many length scales; 4) improved computational and modeling tools focused on enabling predictive design and improvements of proposed technologies, and 5) measurements and standards to enable scale-up and translation of regenerative/tissue engineering products through validation, safety, and control. To meet these needs, NIST should keep pace with the rapid rate of progress in the sophistication of the new materials concepts (3D structure, controlled chemistry, growth factors, bioreactor process design), measurements of cell proliferation and differentiation, including enhanced mechanistic measurements of cell response, and the increasing use of powerful methods such as genome sequencing and metabolomics.

The issues for dental materials are similar to those in regenerative medicine and tissue engineering. The differences lie in 1) the additional need for measurements and validation of microbial, biofilm interactions with the dental restorative material; 2) greater emphasis on mechanical performance and modeling within the oral environment (complicated system) and 3) greater emphasis on the chemistry, dimensional stability, and adhesive properties of the restorative material, especially with respect to an increased attention to the addition of functional properties (e.g. antimicrobial) to the material.

Gene therapies

Gene therapy is the replacement of a defective or maladaptive gene that is responsible for some monogenic disease or inducing production of a therapeutic protein. New forms of nucleic acid-based therapeutics are emerging that appear to be safe and effective. According to representatives from the diagnostic industry who attended a 2008 workshop hosted by the Joint Committee for Traceability in Laboratory Medicine, certain measurement issues are interfering with the speed of innovation. For example, one of these new therapeutic modalities is small interfering RNA (siRNA), a drug that, once injected into cells, inhibits gene expression. siRNA represents a unique measurement challenge because of its size and difficulty to sequence. Measurement science, standards, technology, and measurement services are needed for determination of siRNA parameters such as size, sequence, distribution once injected and concentration inside targeted cells. Other factors are the identification, selection, and validation of delivery of the therapeutic gene to the right cells at the right time. The gene must be delivered without inducing an immune response or change into a pathogenic form. There are also measurement needs related to the efficacy of the gene delivery, intermolecular interactions within the delivery mechanisms and within tissues and cells, and the safety of any given treatment.

Medical devices

The medical devices area is one of the fastest growing in the life sciences with annual revenues approaching $300 billion and current annual growth rates of nearly 15%. One trend in this area is the convergence of medical device products with therapeutic-related technologies with examples such as drug eluting stents or the integration of cellular products with synthetic material scaffolds. NIST can play a role here by developing reference materials and data to support measurement of the composition of the biological or material components of devices. Another area of growth will likely be the development of highly miniaturized biosensors and other medical devices integrated with mobile communication devices such as smart phones for remote, automatic collection, recording, and reporting of patient health data. The vision for these so-called "anticipatory medical devices" is to detect patient abnormalities such as high cholesterol or low blood sugar and correct them before the appearance of any noticeable symptoms. NIST can support this area through development of reference materials and data to aid in characterization of device components, calibration of devices, and their manufacturing. NIST can also play a role in the development of normative data and communication standards and protocols to enable compatible communications platform and interoperable medical devices.

Bioinformatics

Enormous quantities of data are being generated from biological samples by current high-throughput, multiplex technologies based on molecular-level physical and chemical measurements. Moreover, further increases in data volume are expected with advances in instrumentation. With this explosion of data, the extraction of biological information is increasingly hindering progress, leading to increases in both false negative (missed analytes) and false positive (erroneous identifications or quantification) results. While analysis of the underlying physical and chemical data has long been an area of expertise at NIST, analysis of these huge volumes of data containing information for hundreds or thousands of components and the separation of biological information from artifacts is an area new to NIST and in dire need of new expertise. In particular, extension of NIST Standard Reference Materials to include biological samples and measurements of their composition and stability require extensive use of these new technologies – such analysis will require specialists in the area of data analysis and applied statistics. Also, such expertise is essential to properly store, visualize and disseminate such data and to understand the needs of customers who require such biological materials.

Industrial biotechnology
Industrial biotechnology is the application of genomic, proteomic and bioinformatic tools to produce fuels, industrial raw materials, intermediates and consumer goods. Some examples of industrial biotechnology include the production of biofuels from biomass such as cellulose, and production of synthetic fibers for clothing by fermentation from corn starch. Industrial biotechnology is expected to grow dramatically in the coming decade. For example, it is estimated that nearly 20% of the US chemical market uses biotechnology related processes. Also, there are more than 30 existing and planned cellulosic biorefineries set to begin production of biofuels within the next few years. NIST can support industrial biotechnology by developing the underpinning measurement science, reference data, and standards to support improved characterization of genetically modified proteins or organisms used as production systems, their associated biological activity, and the products that these technologies produce.

Safety and Security Sector
In the field of biosafety and biosecurity, the following steps are critical following a biological threat: (1) detection of an event; (2) cleanup and determination of the effectiveness of cleanup after an event; (3) identification of biothreat agent or material; and (4) identification of the source of the material. While several technology platforms are being developed (and a few deployed in the field) that are PCR-based, most of the laboratory confirmatory tests for bacteria are still traditional 'plate-based' culture. The future of biosecurity will include many more molecular based methods employing new genomics and proteomics technologies that will provide quicker determination and confirmation of the presence of a biological threat agent or material. Additionally, new assay methods will be developed and deployed that will be validated for field-use to meet the demands of the responder community. Finally, future technologies may not only be limited to the identification of a single type of agent (bacteria) but will also be able to simultaneously identify and classify other biological threats including viruses and protein toxins. These new assays and technologies will require appropriate measurement infrastructure (standards, data, and methods) to ensure the results are valid for critical public health decisions.

III.b. Projected Skill Sets, Expertise, and Capabilities Needed

Regarding future measurement science in the biosciences, across all sectors it is projected that there will be large growth in the genomics and proteomics areas for which there are numerous applications ranging from microbial identification for food safety to human identification for forensics. In every sector described above, the scientific direction is moving rapidly away from reductionistic research approaches where scientists will study a few proteins or genes and try to draw conclusions on whole organisms. Scientists are embracing systems biology approaches to identify complex multimolecular signatures of health and disease in plants, animals, microbes and ecosystems. This requires simultaneous real-time measurements of thousands of biomolecules and presents unique measurement challenges for which MML needs to be capable of addressing. Therefore, large growth is anticipated for multianalyte, multiparameter, and systems technology platforms and imaging platforms that will perform highly multiplexed and multicomponent biomolecular measurements for applications such as personalized medicine. Thus, MML will require increased biological computation and informatics tools and methods to handle, store, process, and interpret massive amounts of data. Finally, there will also be a demand for new approaches to gather more complete information from complex biological systems to enable molecular and mechanistic understanding of these systems. The continued prioritization of the understanding of complex biological systems has been articulated at the highest levels of the federal government in the OSTP/OMB Updated Administration Research and Development Priorities Memo since 2004.

Other specific areas of bioscience research that are anticipated to experience significant growth in the coming years include biological therapeutics (including protein therapeutics, nanotherapeutics, cell therapies, and vaccines); microbial identification for food safety, environment, human health; and improvements in biomanufacturing processes.

To address future needs where there will be large growth in the areas of genomics and proteomics technologies, we anticipate the need for focused internal growth in these areas as well as in the area of bioinformatics, computation biology, and systems/network analysis to support these efforts. Additionally, advanced imaging capabilities, both whole body and molecular, are needed to address systems measurements in relevant biological systems. Table 3 provides a description of some specific areas that should expand to meet future needs in the bioscience area. In acquiring new expertise and capabilities to meet future demands, we acknowledge the need to develop key strategic partnerships that can complement our internal resources and drive the fundamental biology questions to better serve our industry and public customer needs.

Table 3. Projected growth areas for the biosciences and expertise/capabilities needed to support them

Growth Area	Skill sets, expertise, capabilities needed	Sectors Affected
Genomics and proteomics	- Molecular Imaging - Affinity based measurements - Advanced Sequencing - Mass spectrometry - NMR - Glycoprotein analysis - Immunology - Network analysis - Bioinformatics/biocomputing	- Agriculture Sector - Food / Food Processing - Environment/ Energy - Medical / Scientific Products and Equipment - Safety and Security
Novel Therapeutics	- Imaging (whole body and molecular) - Mass spectrometry - NMR - Sequencing - Bioinformatics/biocomputing	- Medical / Scientific Products and Equipment - Safety and Security
Microbial analysis	- Imaging - Sequencing - Bioinformatics/biocomputing	- Agriculture - Food / Food Processing - Environment/ Energy - Medical / Scientific Products and Equipment - Safety and Security

III.c. Projected Facilities and Equipment Needs
The projected facilities and equipment needs for MML are aligned with the need to improve our expertise and capabilities in key areas including genomics and proteomics, novel therapeutics and microbial analysis. These include:

- New mass spectrometry imaging instrumentation
- New proteomics instrumentation
- Expanded super resolution microscopy systems
- Newly developed 'next' technology sequencing platforms
- Newly developed protein production pilot plant
- Expanded biocomputing/bioinformatics and data storage/archiving center
- Expanded central cell facilities and biospecimen facilities

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Chemical Measurement Science and Standards

Chemical Measurement Science and Standards

The U.S. chemical industry is one of America's top exporters, with $145 billion in annual exports accounting for more than 10 cents of every dollar in total U.S. merchandise exports. Moreover, it is one of America's largest industries and produces annual output worth in excess of $674 billion; this revenue creates jobs for more than five million Americans and is a vital part of our economy, comprising about 2% of our gross domestic product.

The Material Measurement Laboratory (MML) supports this industry via research in chemical measurement science and the provision of tools, data, models, and information that the industry needs to compete, innovate, and thrive in a high-tech, interconnected world. These tools include methods, reference materials, and reference data to support measurements traceable to the SI or other internationally recognized stated references for the identification, quantification, and spatial and temporal examination of chemical species. The provision of reference chemical, thermophysical, and kinetic property data, models, and information is essential for the chemical, chemical engineering, and related technology sectors. These outputs help ensure traceability of field measurements to reliable, world-recognized standards and ultimately contribute to advancing, disseminating, and applying chemical structure, function, and application knowledge for improving the quality of life and communicating the excitement of chemistry to the public. MML does this by strengthening partnerships within the chemical, industrial, environmental, and agricultural communities; growing in-house knowledge of interdisciplinary chemistry-related fields including materials, biology, marine science, healthcare, and informatics; and by informing stakeholders in the federal and private sectors of MML's broad array of capabilities and strengths in the chemical measurement science arena.

I. Current State of the Chemical Measurement Science and Standards at NIST
The MML chemical measurement science function includes fundamental and applied research in chemical metrology, development of chemical measurement methods, and investigations of the phenomena that underpin measurements in chemistry. The MML chemical measurement science function develops and value assigns Standard Reference Materials (SRMs) for chemical composition to enhance chemical measurement comparability within the U.S. and to provide a basis for measurement compatibility with other nations, and establishes the infrastructure to allow commercial production of reference materials with NIST-recognized traceability.

The MML chemical measurement science function includes research to determine the chemistry of surfaces, particles, and materials and their interactions with electrons, photons, ions, atoms, and molecules. These activities range from theoretical to applications research including: (1) determining the geometrical, electronic, optical, and chemical properties as well as isotopic compositions of surfaces, particles, and materials at nanometer scales and below; and (2) determining the energetics, kinetics, mechanisms, and effects of processes occurring in the gas phase, solid and liquid surfaces, and within materials.

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The MML chemical measurement science function includes experimental, theoretical, computational, and simulation studies on: (1) the identity and reactivity of chemical species (including small molecules, aerosols, proteins, nanoparticles and biomolecules) with emphasis on data, information, and protocols for the identification of chemical and biochemical species; (2) the thermochemistry, kinetics, and mechanisms of chemical reactions in the gas and liquid phases and at interfaces; and (3) the properties of gases, liquids, and solids (including mixtures and supercritical fluids) over wide ranges of conditions, emphasizing thermophysical properties (e.g., equation of state, phase behavior, heat capacity, speed of sound, thermal conductivity, viscosity), and interfacial properties (e.g., surface tension, adsorption).

Scientists at MML also engage in research leading to development, implementation, and validation of state-of-the-art computational technologies (including quantum chemistry methodologies, force fields simulations, and chemoinformatics tools) for estimating and predicting chemical and physical properties of single molecules as well as chemical systems in the gas and condensed phase. The MML develops and uses state-of-the-art apparatus to measure thermochemical, thermophysical, kinetic, and mass spectral properties; compiles, evaluates, and correlates chemical property data; and develops, disseminates, and maintains Standard Reference Data (SRD) for important chemical substances and processes. The MML chemical measurement science function also includes research on homogenous and heterogeneous fluid-based physical processes and systems (e.g., separations, regenerative refrigerators, advanced heat transfer systems).

I.a. Fiscal Profile
For the MML the total budget is approximately $137M including $100M in direct appropriations, $21M from other Federal Agencies, and $13.5M from sales of SRMs and SRD. The chemical science function (denoted as the Chemical Measurement Science and Standards Activities in the Feb. 2011 MML funding distribution documents) represents a total of $55M (including $35M direct appropriation, $8M other Federal Agency, and $11M from sales of SRM and SRD) or 40% of the total MML resources. Of these resources identified as Chemical Measurement Science and Standards Activities, 84% of them were identified as impacting the Chemical Community, with the remaining activities impacting the biological or materials communities. Currently, 81% of the MML activities related to SRM and SRD funding are part of the chemical measurement science function. The major MML industry areas based on funding within the Chemical Science Measurements and Standards Activities were: Assessment of Environment and Climate ($18M); Biomedical and Health ($12M); Security, Safety, and Forensics ($11M); Advanced Materials ($6M); Energy ($5M); Food Safety and Nutrition ($4M); and Advanced Electronics ($3M). In this report we will address these areas as the following: Environment, Health (including Food Safety and Nutrition), Security and Safety (including Forensics), and Energy.

I.b. Current Customers and Their Measurement, Standards and Data Needs
In addition to the Federal government and academic communities, a broad range of industrial sectors are served by the MML's chemical measurement science and standards activities via involvement in measurements for chemical composition, structure, or

properties of substances. Customers receive measurement methods, reference materials and standards, critical reference data, and data-predictive computational tools necessary for analysis, control, and optimization of processes pertinent to the sectors identified in Table 1. These products make available flexible, error-tolerant, world-recognized information and tactics necessary to maintain a competitive edge in today's global market. Highlighted below are brief descriptions of current MML activities to meet measurement, standards, and data needs for selected customer sectors. The selected areas called out, as noted by an asterisk in Table 1, are those areas that are served most intensely by MML's metrologically-based competencies and measurement capabilities that are internationally vetted and recognized. The selection of these areas is based upon extensive "conversations" with our customers in these areas and with other national metrological organizations. This dialogue, which is on-going and occurring in "both directions", enables MML to continue to adapt its measurement services portfolio and provide world class services that are relevant and fit-for-purpose for not only the areas called out in greater detail where the conversations may be more intense, but for all of the areas in Table 1.

Table 1. Areas Served by the Material Measurement Laboratory for Chemical Measurements and Standards

AGRICULTURE/ AQUACULTURE
Chemicals
Feed
Fish and Shellfish
Crop Science
Livestock
Soil Science

AUTOMOTIVE/AVIATION/ MARINE
Automobiles and light trucks/vans
Trucks, trailers, and buses
Commercial boats
Aerospace
Engine design
Combustion Modeling

BUILDING/CONSTRUCTION
Building products
Indoor air quality

CHEMICAL INDUSTRY
Chemical sciences and technology
Commodity chemicals
Industrial chemicals
Specialty chemicals
Process chemicals

CONSUMER GOODS
Consumer goods (product safety, chemical composition)

ELECTRICAL/ ELECTRONICS
Consumer electronics and appliances
Electrical Power generation/distribution equipment

ENVIRONMENT*
Fresh Water Resources
Atmospheric and Oceanic Sciences
Biological Resource Management
Pollution Control
Remediation
Climate change: Aerosols and Particulate Matter
Climate change: Greenhouse Gases
Fugitive Gases

ENERGY*
Renewable energy
Natural gas
Pipeline distribution systems
Real Fuels (coal, oil, etc.)
Nuclear energy

HEALTH/NUTRITION*
Health diagnostic devices
Healthcare testing
Quality Management & Assurance
Vitamins/Dietary Supplements

FOOD/FOOD PROCESSING*
Food processing/packaging
Marine fish products
Processed food

INFORMATION TECHNOLOGY/ TELECOMMUNICATIONS
Computer software
Computers and peripherals
Computational technologies and informatics*
Telecommunications equipment
Data systems, curation, and management

MATERIALS
High-tech ceramics
Paper and paperboard
Plastics material and resins
Steel
Alloys
Minerals/ores
Nanotechnology*
Polymers
Dielectrics
Semiconductors
Organic

SAFETY AND SECURITY*
Forensics
Defense
TICs/CWAs
Advanced Sensors

*indicates sector is discussed in text

Chemical Measurement Science and Standards

Building on a hundred-year history of NIST's technical excellence, MML has the most comprehensive array of chemical, physical, and engineering measurement capabilities and expertise of any group worldwide working in chemical science and technology. As noted above, the chemical industry is expansive and is one of America's top exporters. MML provides reference data, theoretical models, and artifact standards that are important to this enterprise. These standards are used for process design and quality control, and helps ensure traceability of field measurements to reliable, world-recognized standards. MML fulfills NIST's mission by addressing customer needs for measurements, standards, and data in the areas broadly encompassed by chemistry, biosciences, and chemical engineering and these activities greatly meet the needs of the environment, health, safety and security, energy, and nanotechnology areas of R&D and economic activity. These selected areas are those which MML has concentrated and strong efforts in, as described below.

I.b.i. The Environment: The MML is aiding industry, government, and academia in the areas of environmental research, remediation and regulation, air and water quality monitoring, assessing climate change, green manufacturing, and policy by advancing measurements and tools for environmental science. This covers a wide range of subjects and approaches such as: calibrating the sensors of climate-mapping satellites for greenhouse gases (GHGs) and aerosols; detecting minute quantities of toxins and pollutants in air, soil, water, and biota; and providing measurements and standards for research into the health and safety of nanomaterials. Some MML personnel are located at the Hollings Marine Laboratory (HML) in Charleston, SC, where they work with scientists from the National Oceanic and Atmospheric Administration (NOAA), the SC Department of Natural Resources, the College of Charleston, and the Medical University of SC to provide the science and standards needed to understand links between environmental conditions and the health of marine organisms and humans.

Helping to establish the scientific basis for measurement and monitoring of substances in the environment that may negatively impact environmental quality and climate is an essential focus of the MML's 40-year lead in environmental data and standards development. The MML Standard Reference Databases provide carefully evaluated data for a variety of substances. One of these, the Mass Spectral Library, contains hundreds of thousands of "signatures" of molecules. This enables the identification of molecular components in complex mixtures of concern to several fields related to pollution monitoring. The MML standards programs support monitoring programs, computational models, and technology to improve the reliability and comparability of measurements. Many of the environmental SRMs have been developed specifically to address the regulations and needs of other agencies including the U.S. Environmental Protection Agency (EPA) and NOAA, including meeting the needs for traceability of measurements related to the oil spill in the Gulf of Mexico in 2010. Currently, MML is developing SRMs and coordinating interlaboratory comparison exercises for laboratories involved in petroleum hydrocarbon analyses for Gulf oil spill monitoring and restoration efforts. The MML additionally supports a specimen banking program (i.e., long-term archiving of environmental specimens) for future retrospective analyses of contaminants in the environment and for health assessment of biota.

With respect to climate, the MML seeks to improve measurements and standards for both GHGs and aerosols. The MML gas concentration standards support cleaner automobiles and power generation and are enabling industry to meet strict emission regulations for GHGs as well as ozone and its depleting species. With respect to automobile emissions, MML works with the American Industry/Government Emissions Research (AIGER) Consortium to facilitate the automobile industry meeting more stringent 2003 Federal and California emission regulations implemented in 2010. MML's work includes maintaining reasonable inventories of required gas SRMs that consist of dilute mixtures of key pollutants such as carbon dioxide, carbon monoxide, hydrocarbons, and nitric oxide. These and additional gas materials also support monitoring programs including the Decadal Observation Series inherent to the World Metrological Organizations Global Atmospheric Watch Program, NOAA's Tall Tower Network, the Total Carbon Column Observing Network, and the Ameriflux/Fluxnet. The MML collaborates with other National Metrology Institutes to establish comparability of GHG measurements. Additionally, the MML develops reference data, measurements, and simulations of global warming potentials of GHGs for use in climate models; the MML evaluation of potential refrigeration fluids with low global warming and ozone depletion potentials is just one example. The MML is providing measurement methods, data, and reference materials to provide better estimates of uncertainties in climate forcing by aerosols in the atmosphere and biosphere. Moreover, the quantitative uncertainties in the measurements of the amount and type of aerosols and aerosol properties are being reduced.

I.b.ii. Health: The MML currently develops the underpinning chemical measurement science, reference measurement methods, and SRMs needed to ensure the accuracy, comparability, and efficacy of chemical measurements used in human clinical diagnostics, nutritional assessment, and biomonitoring. For more than 30 years, NIST has developed and continuously maintained SRMs to support measurements for clinical health status markers such as electrolytes, small molecule biomarkers (cholesterol, creatinine, and glucose), and hormones; nutritional assessment markers (vitamins, fatty acids); and contaminants (toxic metals and persistent organic pollutants). In most instances, the methods developed to value assign these SRMs are based on separations techniques coupled to mass spectrometry. In recent years efforts have expanded to include critically-needed protein health status markers (e.g., troponin I, prostate specific antigen, albumin) by developing methods for the quantification of clinically-relevant protein biomarkers using mass spectrometry-based techniques. In addition to use by industry customers, many of these SRMs are routinely used by other federal and state government agencies such as the Centers for Disease Control and Prevention (CDC) in conducting biomonitoring studies including the National Health and Nutrition Examination Survey (NHANES).

The MML provides food- and dietary supplement-matrix SRMs to facilitate compliance with nutritional labeling laws, provide traceability for food exports, improve the accuracy of label information for packaged foods and supplements, and contribute to studies of human nutritional status. The SRMs are provided to help support compliance with a number of federal regulations enforced by the Food and Drug Administration and the U.S. Department of Agriculture. All current food SRMs are intended for nutritional assessment; none have been developed specifically to address chemical food safety needs.

Another important aspect of MML's current activities in the area of health is the development of robust and accurate metrics and analysis tools for quantifying and understanding the source of the variability in the mass spectrometric data generated in proteomics, metabolomics, and glycomics. Given the complexity of biological fluids such as urine and blood, the development of a reliable metrological infrastructure based on the systematic integration of mass spectrometric measurements and data analysis is central for the development of accurate biomarkers in clinical analysis as well as the manufacture of biological drugs.

I.b.iii. Safety and Security: The MML currently undertakes numerous chemistry-related projects in the public safety and security sector that are primarily driven by the needs of other government agencies. For example, in the realm of public and consumer safety, MML has developed SRMs of lead in paint in both powders and films, responding to the needs of the EPA and the Consumer Product Safety Commission. MML also makes substantial contributions to measurements and standards requirements in the national security arena, principally for customers in the Departments of Defense (DoD) and Homeland Security (DHS). SRMs consisting of trace explosives in both particle and solution forms have been produced to calibrate equipment used for airport screening by the Transportation Security Agency (TSA), and dispensing methods based on inkjet printing have been developed. The entire trace explosive measurement process from sampling to instrumental detection has been investigated with the goal of process optimization, and an ASTM practice for the use of equipment by first responders was written by MML staff. For the DoD, sensors for hazardous gases including chemical warfare agents have been investigated, and methods to detect the isotopic signature from particles of nuclear materials have been advanced for the International Atomic Energy Agency and DoD customers.

I.b.iv. Energy: Chemical measurement science activities related to energy are currently a reasonably sized focus in MML. Fuel quality standards and properties, including SRMs and SRD, are within the current portfolio. Chemistry-related work is underway on aspects of biofuels (including ethanol and biodiesels) as well as fuel cells. MML activities on the hydrogen economy and on solar photovoltaics have chemistry components, including development of hydrogen purity standards and investigations of hydrogen storage materials. Work on fuels includes experimental measurements, computational fluid dynamics, theory, and data development and dissemination focused on kinetics and property studies. The MML develops and maintains numerous fuel-related SRMs (coal, fuel oil, petroleum) for determining mercury, chlorine, and sulfur concentrations in fuels. In addition to the fuel infrastructure, the SRMs are geared towards measurements needed in the electric utilities (for emissions) and for determining coal combustion by-products.

Chemical research on the electronic structure at donor-acceptor interfaces provides a basis for the development of efficient organic photovoltaic cells and devices.

I.b.v. Nanotechnology: The nanotechnology-related activities within the MML include development of novel tools and methods for industries and federal agencies for measuring and imaging chemical substances at the nanoscale, measurement and compilation of data used in nanoscale manufacturing, and development of SRMs and data to accurately quantify and measure the presence and impact of nanomaterials in the environment and biological matrices, including the derivation of nanoparticles from consumer products. These activities are an important component of the MML mission to promote U.S. innovation and industrial competitiveness in the chemical sciences to support all phases of nanotechnology development, from discovery, to production, and to end of life.

I.c. Skill Sets and Facilities

The MML is comprised of some 530 NIST Employees (about 440 Technical Staff) and approximately 350 NIST Associates. Currently, the MML staff involved in the chemical science function includes primarily scientists trained as chemists, chemical engineers, physicists, biologists, and computational scientists. However, in many case the majority of their skills related to chemical measurement science have been acquired at NIST. These skills are divided among experimental/measurements, theoretical, computational, and data related activities. MML staff and affiliates make use of an extensive array of apparatus/instrumentation and facilities in their work on chemical measurement science and standards. Each of the infrastructural and tangible items below is associated with a major or unique experimental or computational facility which involved a significant investment of NIST funds.

Table 2. Skills and Facilities (*and Areas Served*) for Chemical Measurements and Standards

Experimental Skills/Facilities – Cross Cutting:

Electron microscopy [WDS, Auger, EDS, dual-beam systems electron-ion beam (FIB)]
Mass spectrometry (ICP-MS, TIMS, SIMS, GC/MS, LC/MS, LC/MS/MS, MALDI TOF, QTOF, atom probe)
Apparatus and instrument design and development
Atomic spectrometry (ICP-OES, XRF, WDXRF)
Chemical analysis wet laboratories
Laser-based chemical metrology (Near IR, Raman and broadband frequency systems)
Metrological quality experimental programs (e.g., uncertainty assessment, calibrations, traceability)
Nuclear analytical techniques (IMAA, PGAA, RNAA, NDP)
Optical, fluorescence, high-resolution microscopy CC
Optical, FTIR, Raman, and cavity ringdown spectroscopy
Scanned probe methods (topography, surface potential)
Separation science (GC, GCxGC, LC, uHPLC)
Standard reference materials development for measurement of organic and inorganic

species (from percent to ultratrace concentrations)
X-ray methods (fluorescence, diffraction, scattering, reflectivity, crystallography, SAXS, USAXS)

Experimental Skills/Facilities – Energy, Environment:
Fluid property measurements (density, phase equilibria, sound speed, transport properties)
Gas phase, surface, and decomposition thermochemistry, kinetics, and dynamics (shock tube, flash-photolysis, prototype reactors for kinetics of vapor deposition)
Shock-tubes and diffusion chambers
Electrochemistry, pH, electrolytic conductivity, coulometry

Experimental Skills/Facilities – Energy, Nanotechnology:
Atomic and chemical vapor deposition reactors
National Synchrotron Light Source

Experimental Skills/Facilities – Environment, Health :
Cryogenic refrigeration; environments/specimen banking; sample/material preparation; SRM production

Experimental Skills/Facilities – Environment, Safety and Security, Nanotechnology :
Aerosol generation; optical and chemical characterization

Experimental Skills/Facilities – Health, Environment
Nuclear magnetic resonance spectrometry
Microfluidics

Theoretical and Computational Skills/Facilities – Cross-Cutting:
Algorithm development
Computational chemistry and photochemistry
Equations of state
Molecular simulation
Property modeling
Theoretical models

Data-related Skills/Facilities – Cross-Cutting:
Automated data compilation, evaluation, analysis, and dissemination
Chemical and thermophysical informatics
Data entry systems
Data exchange technologies
Data information and management systems
Mass spectral data (chemistry, proteomics, metabolomics, glycomics)
Quality systems for data; uncertainty assessment
Chemical measurement quality assessment programs
Thermochemical, thermophysical, kinetic, and physicochemical property data

Often referred to as the keystone industry because nearly every sector of the manufacturing economy uses its products , the U.S. chemical industry ranks among the world's leading industries, accounting for an estimated one-quarter of total world chemical production. As noted above, MML continuously has extensive "conversations" with this sizable industry and with other national metrological organizations in an effort to accurately sum up the dynamic chemical measurement science and standards activities and needs. MML also considers very seriously information provided on activities and needs directly from the industry and its partners and stakeholders (Appendix). Below in Section II we broadly summarize activities that are on-going within the chemical enterprise nationally and abroad for the five major MML areas: the environment, health, security and safety, energy, and nanotechnology and in Section III we summarize projected future needs.

II. External Environmental Scan for Chemical Measurement Science and Standards
II.a. The Environment: The current drivers in environmental issues include the chemical identification of new classes of emerging environmental contaminants, the need for rapid detection, low-cost, sensitive, and accurate sensors of environmental variables for real-time monitoring, the emergence of "green" manufacturing and products, the development of alternate energy sources including biofuels, and the realization that quantities of quality fresh water may become a problem in the future.

With respect to climate change assessment, GHG emissions are a major driver. Current academic, government, and industrial activities are focused on environmental monitoring and mitigation. The community, driven by the Intergovernmental Panel on Climate Change (IPCC), has been and continues to focus on combined radiative forcing for all anthropogenic agents including long-lived greenhouse gases (CO_2, CH_4, N_2O), industrial gases (CFCs, HCFCs), water vapor (which is a challenge), ozone, and short-lived VOCs. Efforts center on studies of the kinetics/reactivity/mechanisms of atmospheric gases to better understand their global warming potentials (GWP) and oxidation of gas-phase species. Acquisition of GWP data is a major concern for industry; all new industrial compounds introduced to the European market must have a measured GWP, and similar legislation is being considered in the U.S.

There is growing momentum to pursue significant emission cuts for GHGs, and concerted efforts to adopt environmentally clean and efficient technologies are underway. Companies in the Northeast, (e.g., IBM and United Technologies) have set reduction targets and strive to develop products that produce lower levels of heat-trapping emissions during manufacture and/or disposal. Technologies that reduce emissions by capturing CO_2 from fossil electricity generation and either storing it or converting it into useful products are also sought. Policies for reducing vehicle emissions are being examined, including financial support and infrastructure investments to promote the substitution of biodiesel and natural gas for petroleum diesel. The forestry and farming sectors are investigating substitutes for synthetic nitrogen fertilizers (which are energy-intensive) which produce and release heat-trapping nitrous oxides.

Current aerosol research includes investigations on the formation, growth, measurement, and modeling of small particles in gases. Applications include the physics and chemistry of clouds and precipitation, combustion processes, nanoparticle synthesis and measurement, and aerosol instrumentation. Thermodynamic studies, especially the partitioning of particulates between the aerosol and the gas phases, are a focus as well as kinetics studies in the area of aqueous-phase atmospheric reactions involving organic species. Ambient air quality and pollution control research, particularly in bioaerosols, flourishes and includes simulations. Infrastructural property measurements (including vapor pressure, transport properties of mucosal mixtures) are also ongoing activities.

II.b. Healthcare: Much of the work in this field is directed toward the identification of new health and disease markers that can be further developed into clinical diagnostic tools. Similar tools are also applied to the development of new therapeutic agents and methods for monitoring their efficacy. Healthcare-related research is often conducted through an untargeted or "shotgun" approach. This is particularly true in the "omics" fields, including proteomics and metabolomics. An initial set of experiments is performed to refine a research hypothesis and identify specific targets for further investigation. Measurements are often comparative in nature, meaning that the focus is on changes in concentration or chemical properties of the particular target(s) rather than absolute quantification. This field relies heavily upon affinity reagents (antibodies, aptamers, etc.), and these measurement results are often method-dependent. Pharmaceutical companies have started moving away from small molecule therapeutics because many of the traditional disease targets have already been at least partially addressed. These companies see greater potential for expansion in protein-based therapies. The chemical properties of these proteins (glycosylation, phosphorylation, disulfide bridges) have a significant impact on their safety, stability, and activity and are likely to be part of future regulation of these drugs.

II.c. Safety and Security: The safety and security sector has a broad range of needs for chemical measurement science and standards. By its very nature, this sector often requires government involvement. Regulations to ensure safe levels of toxic contaminants in food, water, air, building materials, and consumer products necessitate associated calibration materials and measurement procedures. The increased attention to homeland security since 2001 has created measurement challenges for the stand-off detection of the active components of chemical, radiological, and nuclear weapons. These detection systems are often sited at our ports of entry and other locations within our transportation infrastructure, and their sensitivity and specificity must be characterized with appropriate test materials and procedures.

II.d. Energy: The drivers of energy security and sustainability represent the cornerstones of domestic energy policy. Concerns related to "offer and demand" fluctuations, unrest in the Middle East, or cartel economics, make the use of domestic and alternative sources of fuel a very critical issue. Both the overall impact on the carbon cycle and the concept of renewable supplies are incorporated into sustainability. The most recent policy considerations are based on reducing oil imports and consumption by expanding safe and responsible domestic oil and gas development and production, securing access to diverse and reliable sources of energy, developing alternatives to oil such as biofuels and natural gas, as well as increasing the efficiency of transportation vehicles, homes, and buildings.

II.e. Computational Technologies and Informatics: The use of modern computational methodologies in the prediction of molecular properties has become increasingly important in chemistry and chemical engineering, mainly due to significant improvements in the algorithms and the advent of powerful computer resources. This is particularly true in the areas of thermochemistry and thermophysics, where researchers in industry and academia perform calculations and molecular simulations on a routine basis. Major efforts are being focused at the development and validation of more accurate and computationally efficient methodologies for the prediction of chemical and physical properties of molecular systems of industrial interest. In particular, the combination of theory and simulation methods with chemical informatics tools to correlate structure and properties with chemical and biological functions of molecules has become a center of attention among researchers in industry and academia.

II.f. Nanotechnology: Within the chemical sciences, research and development efforts have focused on discovering new nanoscale structures, measuring the chemical and biochemical properties of these structures, understanding the phenomena that give rise to these properties, and using these insights to create useful substances. Nanotechnology research is highly interdisciplinary. Example of areas where chemistry is making important contributions to nanotechnology include target drug delivery vehicles, methods for sequencing and identifying genetic materials, and self-assembly of complex chemical structures that can be used in electronics and sensing applications.

III. Future State of Chemical Measurement Science (considering a 10 year horizon)
III.a. Projected Future Customer Needs
III.a.i. Chemical Measurement Science: Chemical measurement science required in the future will build on the significant advances in chemical measurement capabilities achieved during the past decade. The application of these advances in chemical measurement science described in this section will apply in all customer areas; more details of future needs will be provided below in the key areas of environment, health, safety and security, energy, and nanotechnology. Trace chemical composition measurements will continue to rely on advances in separation science technologies coupled with detection technologies dominated by mass spectrometry. The need for rapid, highly sensitive, precise, and accurate chemical measurement technology will continue to expand. Nanotrace chemical analysis techniques will be necessary to provide chemical information at nanometer-scale spatial resolution with ultrahigh sensitivity and selectivity using electron beam, ion beam, and surface spectroscopies. Chemical/molecular imaging will be essential, and the future trends will include both electron- and ion-based instruments. With respect to electron-based instruments for high resolution chemical imaging, recent advancements in electron optics will continue to provide smaller/higher-dose electron beams for sample interrogation resulting in routine atomic-scale resolution imaging and analysis. Efforts will continue to advance analytical capabilities in the area of molecular analysis at sub-nanometer resolutions. The continued

development of "atmospheric pressure" sample mounting methods will lead to higher resolution chemical/molecular imaging and analysis of biological specimens both *in vitro* and *in vivo*. Finally, focused ion-beam platforms will continue to develop into multifunction laboratories that provide a wide range of analytical capabilities. With respect to ion-based instruments, future trends for ion/MS imaging will focus in three areas (1) discovery and development of new exotic primary beams involving molecular sources that will be leveraged towards molecular analysis of surfaces with negligible subsurface beam damage, (2) development of smaller/higher density primary beams to improve lateral spatial resolution, and (3) improvement of atmospheric-pressure imaging systems for analysis of samples under non-vacuum conditions.

Methods will be required for sampling and for chemical characterization of heterogeneous materials in small sampling volumes, including characterization of interfacial phenomena, particulate matter, and aerosols. Time-resolved measurements will be necessary for detailed studies of the dynamics of reactions, interfaces, adsorption and desorption phenomena, catalysis, and drug release using spectroscopic techniques capable of detecting single molecules and molecular-scale aggregates and following the time-dependence of chemical reactions, molecular motion, and configuration change with picosecond resolution. There will be increasing need for robust measurement techniques for rapid, real-time, highly reliable analyses in practical environments including on-line analysis to aid process control and environmental monitoring; separation-free analyses; on-line combination of extraction, group isolation, chemical separation, and detection systems to provide accurate measurements of individual compounds in complex matrices.

Management of the profuse chemical information and data required to characterize systems of high complexity (and generated by the instrumentation) will lead to a significant need for modern informatic technologies such as artificial intelligence, neural networks, on-line data reduction, and high-order analysis that can efficiently be used to handle, mine, and analyze the ever increasing amount of data generated by the measurements. Central to these efforts will be the development and validation of efficient and reliable computational tools including quantum chemistry methodologies and molecular simulation models able to treat a wide range of length and time scales, going from the atomic level and a few nanoseconds to process systems engineering at the macrosystem level with a time scale of minutes to hours.

III.a.i.1. The Environment: Future ecosystem health diagnostics will require the development of advanced measurement science and standards to improve the sensitivity, accuracy, and reliability of rapid detection and quantification of analytes in the environment (air, water, soil/sediment) and in biota using laboratory-based analytical methods, biosensors, atmospheric sensors, in-water platforms, and satellite-based remote sensing. Analytes include: pathogens, biotoxins, chemical contaminants (including nanoparticles) and their breakdown products, nutrients, and physiochemical variables (particularly pH, CO_2, salts, and dissolved inorganic carbon). For pollutants and toxins, there is a need for a measurements and standards framework to support biological effects studies, taking into consideration chemical classes and potencies, testing protocols, dose-response relationships, and mixtures. There is also a continued requirement for a measurement and standards framework to support reference materials with linkages to national standards for U.S. environmental policy.

Climate change will be driven by atmospheric and oceanic chemistry and their interaction resulting in chemical and biochemical responses within the ocean. There is a critical need to ensure availability of measurement tools and standards to enable accurate, reliable, and consistent measurements of GHG sources and sinks at various spatial scales. Low-cost, extremely reliable instruments are needed. In addition, chemical and physical reference data to support SI-traceable measurements of the Global Climate Observing System (GCOS) Essential Climate Variables, which are used to monitor the climate system and assess the impact of climate variability, are needed. There are also huge spectroscopic data and gaps that need to be filled, in particular the spectroscopic strength of minor gases. Chemical metrology will be required in the laboratory as well as in field measurements and observations for both GHGs and aerosols. For aerosols, techniques for the generation of aerosols in the laboratory will continue to be needed. Additionally, advances in aerosol measurement methods, such as optical properties and physical properties will be critical. Related to this are properties of aerosol precursors, such as the oxidized pinenes that contribute to smog. We will also require the development of simulation metrology to meet cases where measurements are not possible. Along with such SRD activities, are SRM work, including standards for calibrating or evaluating current measurement procedures for ambient aerosol size/morphology, CCN (cloud condensation nuclei), and aerosol absorption.

With respect to meeting the future needs in sustainability in goods and services, advancing measurement science and standards will be important. Future sustainability in the chemical industry will require technological advances for carrying out new chemical transformations using green chemistry/engineering, new tools for comparing environmental impacts of products using different processing routes, new computational and genomic tools for improved understanding of structure-function relationships for chemicals in the environment, and measurements and standards to support the advancement of derivation of chemicals from biomass.

III.a.i.2. Health: Many of the future chemical measurement challenges related to health are identified in report of the NIST conference "Accelerating Innovation in 21st Century Biosciences: Identifying the Measurement, Standards, and Technological Challenges". To a large extent, the future of chemical measurements and standards to support the health sector will be driven by the needs of the emerging "omics" (e.g., proteomics, metabolomics, glycomics, lipidomics). The "omics" rely on multiplexed analytical techniques that integrate disparate measurement technologies for measuring a multitude of diverse chemical species to provide reliable identification and quantitation in various biological matrices. Research in the "omics" is highly dependent upon chemical species identification, thereby requiring high-quality databases with associated spectral libraries to support accurate identification. Additional complexity arises from the fact that merely identifying a set of proteins as potential markers is not sufficient. Modifications to the protein, such as phosphorylation or the incorporation of metal species, play a significant role in their activity but are often transient in nature. Standardization of these measurements will require quantification of the biologically relevant form of the protein, which may vary for different applications.

Therapeutic and preventive intervention in medicine will be based on "disease signatures" – unique descriptors for individuals that are definitive markers of health status and that are derived from the integration of qualitative and quantitative measurements, including thousands of measurements of chemical species. The next generation of health assessment diagnostic tests will be based on these complex signatures rather than single markers. Standardization and comparability of such multiplex measurements across measurement platforms, among laboratories, and over time will be critical. Future delivery of measurement methods and standards to the health sector will require new ways of providing SRMs and associated characterization data. Central to the success of these efforts will be the development, implementation, and validation of effective and accurate chemo- and bio-informatics tools to enable researchers and clinicians to handle and analyze on a routine basis the massive and complex sets of data produced.

III.a.i.3. Safety and Security: The consumer safety and security sector will continue to require the measurements, standards, and data support of NIST over the next 10 years and into the foreseeable future. To assure the safety of food and water supplies, there will be an increasing need to establish analytical methods, SRMs, and measurement assurance programs for detecting, identifying, and measuring levels of harmful microorganisms, food allergens, protein toxins, and other substances, including synthetic materials, of particular concern to food and water safety. Increasing concern about the health effects of nanomaterials will provide new measurement challenges. In particular, it will be necessary to identify, modify, or develop the measurement tools to quantify and characterize the chemical aspects of nanomaterials along the product life cycle and in biological and environmental systems. More precise instruments will enable accurate and reproducible results and provide better risk assessment and risk management.

For external national security issues, the priorities will continue to be set by the DoD, but there are likely to be numerous focus areas in MML mission space, such as improved sensors for chemical warfare agents. The existing MML program providing measurements and standards for the detection of nuclear materials will remain a priority area. Internal national security requirements will continue to be driven primarily by DHS. The desire for improved speed, sensitivity, and reliability of detectors of chemical, biological, and radiological agents will have associated testing requirements before deployment. Protection of our transportation systems is likely to receive increasing attention, especially marine shipping and port facilities. The need for MML support of the TSA in providing unbiased evaluation methods and reference materials for explosives detection technologies will continue and expand.

Forensic science in the U.S. is an area that is in critical need of improvements in scientific foundation, measurement rigor, and statistical validity according to a recent report from the National Academy of Sciences. MML should play a significant role in developing the tools for advancing chemical measurements, validation, and reliability in this area.

III.a.i.4. Energy: Chemical measurement science and standards will continue to be required within the National goals of sustainability and independence in the energy sector. The evolution away from traditional petroleum resources will initially require innovative, efficient, environmentally benign, and safe discovery, extraction, processing, conversion, distribution, and combustion of alternative sources of fuels. Chemical measurements and protocols, SRMs, and SRD will be needed for composition/trace analysis as well as for the different facets of the manufacture of these fuels including quality control, catalysis and separations, and additive design. The "green" exploitation of coal reserves as well as the development of cost effective carbon sequestration and separation processes will require significant investments in chemical metrology. Geochemistry is a factor in most of these resources, and a fundamental understanding of the aqueous chemistry will be become critical for some extraction, processing, and environmental considerations. Major advances in solar technologies will continue to rely on photovoltaic chemistry, electrochemical energy storage, and thermal management. Similarly, the use of hydrogen, including efficient electrolysis and fuel cell advances, will rely on the detection and characterization of trace contaminants as well as the chemistry of interfaces. The safe production of electrical (and thermal) energy through nuclear technology will require innovation and standards in radiochemistry, thermal management, materials chemistry, advanced cycle chemistry, and studies of the interaction of the radionuclides with the environment.

In the area of biofuels, measurements and SRD needs associated with biochemical and thermochemical conversion processes will become important. The ability to efficiently process diverse and de-centralized feedstocks, as well as the effective biochemical interface between crop development and processing to biofuels will pose new metrological challenges requiring chemical measurements and data. Finally, one of the biggest challenges in the energy sector will be the determination of robust metrics for sustainability. Standards generated with the help of efficient and reliable chemical informatics tools will be an important part of such a program for certifications of sources, sustainability, and life cycle impact.

III.a.i.5. Nanotechnology: Tools capable of characterizing the chemical composition and other properties of nanoscale materials, in real-time and in three dimensions are required. These will integrate multiple probe types and bridge multiple length scales. Properties of interest include hardness/ductility, optical, electronic, mass transport, reactivity, magnetism, and thermo- and piezoelectric properties. These tools should be capable of characterizing buried interfaces. Commercial applications of this technology include inspection/quality control and combinatorial screening. A variety of physiochemical techniques are used in the manufacturing of nanoscale materials and structures. These include self-assembly, chemical vapor deposition, atomic layer deposition, electrochemistry, and other methods. In many cases the underlying chemical pathway and rates are unknown. This lack of knowledge is a barrier to use of these processes in industrial settings, most notably in the manufacturing of nanoscale electronic components. In many cases the raw material requirement for nanoscale chemical and material processing will be different from the requirements for macroscale manufacturing, and thus different SRMs will be required.

Modeling is an important element of nanotechnology. Existing algorithms and data sets are inadequate for modeling chemical processes relevant to industry. Comparisons between various models and reference-quality measurements are needed, and methods that include error-estimations must be developed.

III.b. New Skills Sets and Facilities Required to Meet Customer Needs
III.b.i. Expertise: The current MML staff, who are trained in chemistry, chemical engineering, biology, or physics, have shown in the past to be versatile and flexible in adapting their skills to new programmatic areas requiring chemical measurement science. For example, the staff involved in providing chemical measurements in environmental, food, clinical, or fuel materials, are typically trained in analytical chemistry rather than environmental, food science, clinical, or fuel chemistry and can readily adapt to address the measurement problems in these areas. Therefore, as MML moves into new areas, the existing skill sets in chemistry, chemical engineering, physics, and biology will continue to meet the majority of the needs. For the chemical measurement science function, MML will continue to require staff predominantly with training and skills in analytical chemistry, physical chemistry, biochemistry, chemical engineering, biology, and physics. The recent trend within MML to hire biologists and biochemists because of expansion into the bio-related activities, and then train them in chemical measurement science will continue with growth in the health and environment areas. As described previously, the expanding data generation capabilities of current and future instrumentation, particularly mass spectrometry-based instruments, requires staff with skills in chemoinformatics and data mining which will be essential to serving MML's current capabilities (Table 1) and meeting the cross-cutting future needs in the environment, health, and safety and security areas.

Specific areas that will need to be hired or developed to meet the future needs described previously (and the areas served) are listed below. These are generally listed in order of need to best meet the future measurement, standards, and data requirements for the chemical enterprise.

- Expanded expertise in advanced mass spectrometry techniques (environment, health, safety and security, energy)
- Expanded expertise in information technology (environment, health, safety and security, energy)
- Expanded expertise in bioinformatics and chemoinformatics applications to large datasets (environment, health, safety and security)
- New expertise in biotoxin identifications using MS and NMR techniques (environment, health, safety and security)
- New expertise in protein modifications (characterizing phosphorylation, etc.) and in assessing protein stability (environment, health)
- Expanded expertise/capabilities for peptide synthesis (environment, health)
- Expanded expertise in protein expression and purification (environment, health)

- Expanded expertise in nanoparticle characterization in environmental and biological systems and speciation related to nanoparticles (environment, health, safety and security, nanotechnology)
- Expanded expertise in chemical modeling (environment, health, safety and security, energy, nanotechnology)
- Expanded expertise in modern simulations and informatics technologies that can efficiently be used to handle, mine and analyze the large amounts of data (environment, health, safety and security, energy)
- Expanded radiochemical expertise (safety and security, energy)
- New expertise in food toxin and allergen measurements (health, safety and security)
- Expanded expertise in bio- and chemical engineering as related to measurement standards for next generation rapid/accurate environmental sensors (environment, health)
- Expanded expertise in integrating "omics" (genomics, proteomics, lipodomics, metabolomics) (environment, health, safety and security)
- New expertise in directed self-assembly (health, nanotechnology)
- Expanded advanced scanning probe instruments and other nanoscale characterization tools (nanotechnology)

III.b.ii. Equipment and Facilities

Chemical measurements, particularly in the environment and health areas, will increasingly rely on mass spectrometry-based measurement systems and hyphenated separation and mass spectrometry systems. Mass spectrometry instrumentation is advancing rapidly in capabilities (sensitivity, speed, data handling), and MML will need to maintain state-of-the-art mass spectrometry instrumentation and facilities (increasing numbers of instruments and diversity of MS techniques) to keep pace with the expanding measurement needs. Better sensitivity, single atom sensitivity, and molecular sensing rather than elemental will be needed. Continuous upgrades to microscopy and spectroscopy capabilities will be required. In addition, continuous upgrades to the existing computational resources (including hardware and software) to support the chemo- and bio-informatics needs mentioned in the previous section. Given the amount of data expected to be generated/analyzed, MML will need data storage facilities in the order of petabytes as well as parallel architectures based on state-of-the-art processors such as GPUs. In addition, access to large-scale computational infrastructures such as Cloud and Teragrid Computing might be also necessary.

With the development of next generation SRMs, the MML will need to expand and improve the current facilities for preparation of SRMs/RMs, including capabilities for small volumes of solutions, advanced large scale mixing, and on-line homogeneity testing for moisture. Lastly, the energy future research needs will require a test engine facility that includes spark ignition, compression ignition, and gas turbine test engines with optical access and laser diagnostics. This test facility will be essential support for the evolution away from traditional petroleum resources.

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Materials Measurement Science and Standards

Materials Measurement Science and Standards

I.Introduction

Many technologies that are critical to the health of our economy hinge upon the design, development and use of materials. As such, materials are often central to technological innovation, since it is their properties that impart products with performance and functionality. For example, the revolutionary smaller and faster electronic devices we enjoy today are only possible because of advanced semiconductor and packaging materials. In addition, current and emerging technologies for renewable energy, energy efficiency and storage, sustainability, homeland security and defense, and biotechnology all depend upon the design, development and commercialization of materials that exhibit new or improved properties.

The development, production and application of materials in manufacturing and technology represent a significant portion of U.S. economic activity. For mineral-based materials alone, the value of products manufactured in the U.S. exceeds $400B, and U.S. plastics products accounts for nearly $380B [1]. In addition, advanced materials have been essential to innovation in key U.S. manufacturing sectors, including the $550B electronics industry, the $300B automotive industry, and the $200B aerospace industry [2]. However, to reap the economic and technological benefits of materials, industry and other government agencies face considerable challenges, as they must be able to optimize their properties, effectively manufacture reliable products from them, and assess their safety and environmental impact, among other issues.

The NIST Materials Measurement Laboratory provides measurement science, standards, instrumentation and data that enable and accelerate the development and application of materials, from metallic alloys, semiconductors, and polymers to nanomaterials and hybrids. These measurement tools provide the accurate assessments of materials composition, structure, and properties needed by industry and other government agencies to design and optimize materials, manufacturing routes suitable for advanced materials processing, achieve quality control, comply with regulations, and ensure the long term reliability of products produced with materials.

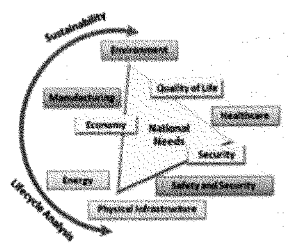

Fig.1 National needs (yellow boxes) and national priority areas that depend upon materials innovation (other boxes). The positions of the national priority areas relative to the national needs indicates their relevance to the needs. The curved arrow indicates the increasing focus on sustainability and the product lifecycle concept in materials science.

II.Environmental Scan

II.a.*Scan of Materials Trends*

Materials have been and will continue to be key enablers of our Nation's economic growth, security, and quality of life. The primary National Priority Areas [3] for which materials advances will play a pivotal role in technological innovation include energy, the environment, healthcare, manufacturing, physical infrastructure, and safety and security, as depicted in Fig. 1. Over the last century, materials advances have been characterized by two trends: (1)

efforts to refine and optimize the composition and structure of bulk-scale materials, with the goal of producing superior material properties; and (2) integration of disparate materials at ever decreasing length scales, resulting in components and devices with new or improved performance. An example of the former trend is light-weight, high-strength aluminum alloys for aircraft applications. The latter trend is exemplified by the integrated metal-ceramic-polymer multilayer structures that provide smaller, lighter, and faster microelectronic devices. This trend has continued in the 21st century with the advent of engineered composite nanomaterials [4], all the way to hybrid materials with inorganic-organic bonding at the molecular scale [5]. For manufacturers, the enterprise of empirical structure, properties, and process optimization of such complex materials can mean considerable expenditures of time and money. Hence, the 21st century has been marked by the need for validated predictive models that will leverage the emergence of increasingly powerful computers to enable a "materials by design" approach to materials and process optimization [6]. An additional 21st century issue is sustainability—meeting today's needs without compromising the needs of the future—as an overarching consideration that will place constraints on the development and application of materials for national priority areas [7], but will also present new opportunities for materials-driven innovation. Finally, lifecycle analysis of materials and their products has become increasingly important as a result of growing concerns of environmental impact, energy conservation, and scarcity of critical materials [8].

II.b. *Scan of Customers and Their Measurement, Standards, and Data Needs*
Current and potential MML customers in materials are incredibly diverse, and include a large number of industry sectors, as well as other federal agencies, universities, and non-governmental organizations, both national and international. Table 1 gives a sense of the wide range of industry sectors for which materials, and materials measurements, are important. This list derived from the DoC Industry Exporters list [9], and will be used throughout our report. In addition, there are many federal agencies with materials measurement needs, including Departments and their organizational units and independent agencies.

Table 1. Relevant industry customer sectors for materials

Agriculture	Energy*	Materials/Chemicals
Automotive/Aviation/Marine	Environmental	Medical Products and Equipment
Building/Construction/Hardware	Food/Food Processing	Safety and Security
Consumer Goods	Health and Beauty/Fashion[#]	Sports and Recreation
Electrical/Electronics	Industrial Equipment	

*previously included in Environmental; [#]vitamins, cosmetics and personal care, toiletries, fabrics, apparel

As a model for capturing the huge breadth of potential customers related to materials and their measurement and data needs, one can consider different aspects of a material-product lifecycle as shown in Fig. 2. Through this lens, six general classes or groups of customers emerge: Developers of Materials, Producers of Materials,[1] Manufacturers of Products,[2] Users of Products, Recyclers of Materials and Products, and Disposers of Materials and Products. As shown in Figure 2, each customer group has specific needs for measurements; for example, materials identification, process optimization, and environmental impact. MML's response to any single customer or customer industry sector can be analyzed with this model, so it will be employed as a tool throughout this report.

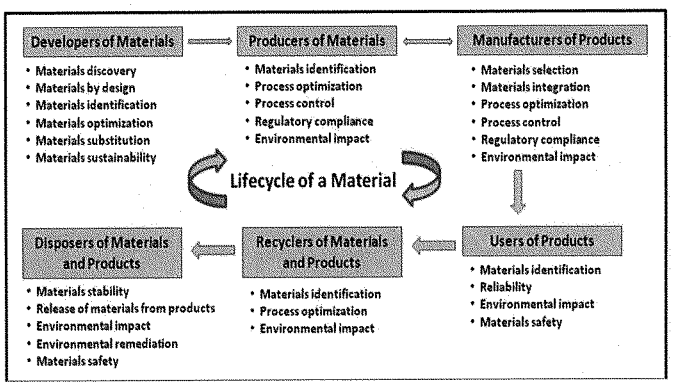

Fig. 2 *Lifecycle of a material, showing the groups of customers and their measurement needs. Definitions of the customer groups and their measurement needs are provided in Appendix A.*

III. Current State of Materials Science Activities at NIST

III.a. *Scope of MML Research and Measurement Service Activities*

The following scoping statement was developed for MML to describe and delineate materials science measurements and standards activities that are consistent with the NIST mission. The three elements of this scope are:

- Research in materials science and engineering to establish the underlying *processing-structure-property relationships* of technologically and commercially relevant materials
- Provision of measurement tools—*instruments, protocols, reference materials, models, and software*—that enable accurate, precise, and reproducible measurements of:
  - Material composition[3] (C)
  - Material structure[4] (S)

[1] Both "commodity" materials, *e.g.,* steel, cement, polyethylene, and specialty materials.
[2] that contain materials, *i.e.,* components, structures, devices, systems
[3] includes spatial and temporal distributions

  - Material properties[5] (P)

  Such tools enable the design, development, manufacture, and sustainable use of such material, and the optimization of materials processing and production, performance, and reliability of components, devices, and systems that incorporate such materials
- Provision of benchmark and Reference data for material composition, structure, and properties

As it stresses alignment with the NIST mission, this scoping statement provides a general frame for describing what MML does in materials now, and clarifies the type and nature of the work expected from potential future activities.

III.b. *Fiscal Profile in FY11*

Across all of MML, the investment in Materials Science was about $ 56.0 M out of the total MML FY11 funding of $ 137.2M, equivalent to 41.6%. In FY11, MML defined a list of eight major program areas, most of which include materials related measurements and standards activities. The funding distribution for Materials Science activities among these areas is presented in Table 2. The largest efforts are in the Advanced Electronics, Advanced Materials, Biomedical and Health, and Energy Program Areas. For this exercise, Advanced Materials included all activities in manufacturing except electronics, and also included all measurement activities that are relevant to more than one program area, *e.g.*, standards for calibrating broadly applicable instruments.

Table 2. Funding for materials science activities in the MML Program Areas

MML Program Area	STRS Funds, $k	Other Agency Funds, $k	MML Program Area	STRS Funds, $k	Other Agency Funds, $k
Advanced Electronics	11,624	531	Biomedical and Health	6,753	2,136
Advanced Materials	19,019	3,385	Physical Infrastructure	3,413	1,311
Environment and Climate	2,893	275	Energy	10,261	1,045
Food Safety and Nutrition	0	0	Security, Safety, and Forensics	1,126	5,207

III.c. *Current Customers and Their Measurements, Standards, and Data Needs*

To assess the current customer focus of NIST materials science activities, two models to sort customer sets were used: the six groups and their measurement needs shown in Fig. 2 and the industry sectors listed in Table 1. Other agencies served by MML research were also examined. The materials-focused Divisions reported on activities for the first two

[4] includes electronic, molecular, and macromolecular structure, chemical and atomic arrangements, microstructure, and dimensions

[5] mechanical, thermal, electrical, magnetic, optical, and chemical properties under equilibrium, non-equilibrium, and dynamic conditions

groups. Tables 3 and 4 summarize the relative level of the MML effort—high (H), medium (M), or low (L)—for these two customer types.

Customer Groups

Within the context of the materials lifecycle shown in Figure 2, MML works predominately within the "upstream" part of the lifecycle, *i.e.*, Developers and Producers of materials. By comparison, MML has little to no activities within the "downstream" parts of the lifecycle (e.g. serving Recyclers and Disposers) and provides only modest support for Manufacturers. In terms of the measurement needs of MML customers, MML works predominately on establishing measurements related to materials development, largely through composition and structure measurements for materials identification and discovery, and on developing measurements for materials and process optimization, largely by establishing and improving property measurements. In contrast, MML has little activity in developing measurements in support of "downstream" needs, such as materials sustainability and recycling, materials safety and stability, and environmental impact. These seemingly underserved areas represent potential gaps for MML to address in the future if they align with significant emerging industrial or national measurement challenges.

Table 3. Current customer groups and their measurement needs, listed in approximate "upstream to downstream" order

Customer Group	MML effort
Developers	H
Producers	H
Manufacturers	M
Users	M
Recyclers	L
Disposers	L

Measurement Needs	MML effort	Measurement Needs	MML effort
Materials discovery	M	Environmental impact	L
Materials by design	L	Materials selection	M
Materials identification	H	Materials integration	M
Materials optimization	H	Reliability	M
Materials substitution	M	Materials safety	L
Materials sustainability	L	Materials stability	L
Process optimization	H	Release of materials from products	L
Process control	L	Environmental remediation	L
Regulatory compliance	M		

Industry Sectors

Table 4 maps the materials-relevant industry sectors from the DoC industry exporters list to seven of the eight MML Program Areas (there are no current materials science activities in the MML Food Safety and Nutrition Program Area), and ranks the level of MML effort. As might be expected, MML has extensive measurement activities that serve the Materials sector; additional areas of emphasis are Electronics and Energy. As noted above, much of this work is aimed at advancing the materials development for these sectors. Consistent with the small levels of effort in the downstream measurement needs noted above, MML has limited measurement activities in the Environmental sector. Efforts that directly support manufacturing are modest overall, and are strongest in the Electronics and Automotive sectors.

Table 4. Current MML Industry Customer Sectors adapted from the DoC list

Industry Sector	MML Program Area	MML effort
Automotive/Aviation	Advanced Materials	M
Building/Construction	Physical Infrastructure	M
Consumer Goods	Advanced Materials	L
Electronics	Electronics	H
Energy	Energy	H
Environmental	The Environment	L
Health and Beauty/Fashion	Advanced Materials	L
Materials	Advanced Materials	H
Medical Products and Equipment	Healthcare	M
Safety and Security	Safety, Security, and Forensics	M

A few significant examples of MML materials-focused activities for each industry sector-MML Program Area from Table 4 are listed below:

- Automotive/Aviation: *sheet metal forming; automotive light-weighting; crashworthiness*
- Building/Construction: *materials and structural performance under extreme conditions; non-destructive evaluation of infrastructure components*
- Consumer Products: *coatings, paints, adhesives, synthetic fibers*
- Electronics: semiconductor *microelectronics, magnetic data storage;MEMS devices; flexible electronics; post-CMOS electronics; electronic nanostructures*
- Energy: *power generation: renewable energy (photovoltaics, thermoelectric, biofuels), nuclear infrastructure safety, hydrogen; pipeline materials (hydrogen, gas, petroleum, biofuels); storage (batteries, hydrogen); fuel cells;*
- Environmental: *nanomaterials environmental, health, and safety issues (nano-EHS); carbon sequestration; climate change*
- Health and Beauty/Fashion: *personal care products; complex fluids*
- Materials: *measurements, standards, and data applicable to multiple materials in multiple industry sectors (e.g., standards to calibrate commonly used instruments); processing; high-throughput approaches to support materials development*
- Medical Products and Equipment: *dental materials; implantable medical devices; tissue engineering; nanoparticles for cancer treatment; medical imaging*
- Safety and Security: *forensics, including explosive agent detection; incident assignment; body armor reliability*

Other agency customers

MML works with many federal agencies, and receives financial support from the Department of Defense, Department of Homeland Security, the National Institutes of Health, the Department of Transportation, the Department of Energy, the Department of Justice, and the Nuclear Regulatory Commission, in order of decreasing support. Other agency support is primarily in the areas of safety and security, in particular forensics, explosive detection and ballistics protection, materials for dental health, nanomaterials environmental health and safety, infrastructure remediation and energy infrastructure safety and reliability.

III.d. ***Current MML Capabilities for Measurements, Standards, and Data***
MML researchers currently have an extensive portfolio of capabilities, defined here as skills, expertise, facilities, and instruments, for developing measurements and standards for C, S, and P of materials, both solid and fluid. The skills and expertise include experimental measurements, analysis using theory, modeling, and computation, synthesis and fabrication of materials and structures, and expert knowledge of all classes of materials with characteristic length scales ranging from the nanoscale to the macroscale. MML researchers also maintain a broad portfolio of experimental facilities for C, S, and P measurements, including a number of world-class instruments. Two major emphases of this capabilities portfolio contained within all the materials-focused MML Divisions are the determination of composition and structure and the measurement of mechanical properties. Structure determination capabilities extend from the sub-nanometer electronic scale to the sub-millimeter microstructural scale and include the use of all forms of probing radiation and contact and non-contact microscopies. Mechanical property measurement capabilities extend from the nano-scale to the macro-scale and include all modes of mechanical deformation.

MML Experimental Measurement Capabilities
The areas for which MML has world-class measurement capabilities, in terms of staff skills and expertise and associated facilities that include a mix of world-class (one of a few) and commercial state-of-the-art instruments, are presented in Table 5. Here "facility" is defined as a collective group of instruments that reside in one or more Divisions and locations, including the Gaithersburg and Boulder sites and the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory[6]. The NIST Center for Neutron Research (NCNR) is included because of the many interactions between MML and NCNR. Each facility listed below represents a capital investment of $ 5M to $ 25M, and includes one or more world-class instruments. The facilities are sorted by the core materials measurement capabilities they support, i.e. the quantification of material's composition, structure and properties. In addition to the materials properties assessment capabilities given in Table 5, MML has lesser capabilities in electrical and optical properties measurements.

Table 5. Major MML experimental measurement capabilities and measurement types

Core Measurement	Major Facilities	Primary measurement types

[6] At the NSLS, NIST has eight resident researchers and owns, operates, maintains, and develops new capabilities at five beamlines at NSLS

Capabilities		
Materials Composition and Structure	Electron microscopy methods	diffraction (S), spectroscopy (C), imaging (C, S)
	Laboratory X-ray-based characterization methods	diffraction (S), reflectivity (C, S), scattering (S), spectroscopy (C), imaging (C, S)
	Synchrotron X-ray-based characterization methods	scattering (S), spectroscopy (C, S), imaging (C, S), diffraction (S), reflectivity (C, S)
	Neutron-based characterization methods (NCNR)	diffraction (S), reflectivity (C, S), scattering (S), activation analysis (C), imaging (C, S)
	Ion-based characterization methods	mass spectrometry (C, S); mass spectrometric imaging (C,S)
	Optical characterization methods	spectroscopy (C, S), spectroscopic microscopy (C, S)
	Scanning-probe microscopy methods	topography (S), spectroscopic microscopy (C, S)
Materials Properties	Mechanical properties methods	elastic (P), plastic (P), fracture (P), and rheological (P)
	Magnetic properties methods	magnetization (P), hysteresis (P), domain motion (P)
	Thermal properties methods	thermodynamic (P), transport (P), especially fluids
	Chemical properties methods	Equations of state (C), solubility (P), chemical transport and reactions (P)

MML Analysis Skills and Expertise

The analysis skill sets in MML Divisions includes a strong emphasis on the prediction of structure, particularly at the atomic and molecular scale, with structure modeling and simulation skills and expertise contained within the MML Divisions. Structural modeling and simulation expertise include: First principles calculations, molecular dynamics and potential function-based calculations, field- and phase-based models, and phase diagram calculations for metals and fluids. In addition, there are theoretical skills and expertise in structure and properties in the areas of crystallography, magnetics, statistical optimization, thermodynamics and kinetics, chemistry, and mechanics. Computation plays a large role in nearly all the analysis activities and there are skills and expertise in computational property prediction and simulation using finite element analysis, computational fluid dynamics, and computational chemistry.

MML Synthesis, Fabrication and Processing Capabilities

Synthesis and fabrication capabilities are an essential part of MML function when they provide a testbed or finely controlled model specimens to advance measurement development. MML skills, expertise, and instruments, have a strong emphasis on producing solid structures with nano- or micro-scale dimensions, including thin-film deposition via liquid and vapor phases, nanomaterial synthesis, separations, microfabrication (including the NIST Center for Nanotechnology Science and Technology (CNST) and the Boulder Precision Measurement Laboratory nanofabrication facilities), surface functionalization, and molecular self-assembly. The predominant bulk-scale materials synthesis and fabrication capabilities are related to polymer processing and sheet metal forming.

MML Materials Expertise

The materials expertise within MML extends across all material classes—ceramics, metals, polymers, semiconductors, composites, biomaterials, and fluid materials—in bulk, particulate, and multilayer forms. There is a strong focus within each class on materials of commercial importance, and increasing expertise in biomaterials and nanomaterials. In addition, MML staff have strong knowledge of the technology areas and associated industry sectors for which materials play a central role.

NIST Materials Measurement Capabilities Outside of MML

Materials measurement capabilities also exist within the NIST Physical Measurement Laboratory (PML), Engineering Laboratory (EL), the CNST, and NCNR. The principal capabilities within each laboratory are:

- **PML**: optical and light-matter interactions (S, P), electronic properties of semiconductors (P), shape and spatial chemical distributions of nanostructured materials (S)
- **EL**: mechanical behavior of structural materials (P), stability, weathering, and flammability resistance (C, S, P), concrete structure and stability predictions (C, S, P), service life predictions (S, P)
- **CNST**: microfabrication and processing in the NIST Nanofab. (C, S), nanofabrication (C, S), electrical, magnetic, and optical measurements at the nanoscale (P)
- **NCNR**: neutron scattering and diffraction (C, S)

Although these laboratories maintain material measurement capabilities, their focus is generally not on the central theme of materials science, to establish processing-structure-properties relationships, or the focus of MML, on technologically and commercially relevant materials.

IV.Future State of Materials Science Activities at NIST: 10 year horizon

IV.a. ***External Assessment***

The team conducted an extensive survey of numerous materials-related technology roadmaps [10-26]. The results of this survey, along with expert knowledge, have been used to assess the future state of materials science in terms of National Priority Areas, technology priority areas, MML Program Areas, customers, and measurement needs and solutions. Tables 6-9 summarize these assessments and are used to establish MML materials measurement priorities. Table 6 lists materials-focused technology priority areas within the National Priority and MML Program Areas. For each of these items, it is noted whether the needs in the area could be addressed by expansion or redirection of current MML activities (e/r), or that it reflects a substantially new direction for the organization (n).

Table 6. Materials-focused technology priority areas

National Priority Area	Example Technology Priority Areas	MML Program Area(s)

National Priority Area	Example Technology Priority Areas	MML Program Area(s)
Energy	Lower cost and greater efficiency photovoltaic materials for renewable energy (e/r)	Energy
	Improved biofuel production processes for renewable energy (e/r)	
	Lower cost and greater energy density materials for batteries for energy storage (n)	
	Lower cost and greater energy density materials for hydrogen storage and fuel cells (e/r)	
	Lower cost and more reliable solid state lighting materials for energy efficiency (n)	
	Materials for low grade thermal energy recovery and energy harvesting (e/r)	
	Materials to improve building environment efficiency (n)	
	Materials for design and construction of safe next generation nuclear plants (n)	
Environment	Materials substitution to enable toxic and critical materials reduction (n)	Environment and Climate
	Methods to enable sustainable bio-based and recycled materials feedstocks (n)	
	Methods to assess nanomaterials in the environment (e/r)	
	Methods to assess the release of nanomaterials from products (n)	
	Cost effective, reliable materials for carbon sequestration, water filtration, and environmental remediation (e/r)	
Healthcare	Bio-stable and -resorbable materials for regenerative medicine and implantable medical devices (e/r)	Biomedical and Health
	Infection resistant materials for medical devices and products (n)	
	Materials and media to enhance preservation of proteins, pharmaceuticals, and vaccines (e/r)	
	Methods to assess the reliability of implantable electronic medical components and coatings (e/r)	
	Lower cost and greater sensitivity materials for enhanced medical imaging and diagnostics (n)	
Manufacturing	Methods to accelerate development of materials and processes for cost-effective manufacturing (n)	Advanced Electronics Advanced Materials Energy Environment and Climate
	Methods to enable reliable, automated, high-volume processing of advanced materials for cost-effective manufacturing (n)	
	Methods to enable ease of environmental regulatory compliance during materials and product manufacturing (n)	
	Increased materials recycling and energy efficiency of materials processing for sustainability (n)	
	Materials with greater strength-to-weight ratio to enable vehicular light-weighting and reduce energy consumption and emissions (e/r)	
	Materials to improve vehicle crash worthiness and resist impact failure to improve transportation safety (e/r)	
Electronics	Materials to enable post-CMOS microelectronics technology for increased energy efficiency and computational speed (e/r)	
	Life cycle analyses of information technology materials to enable sustainability (n)	
	Standardized foundry processes, tests and calibrations to enable high-volume manufacturing of emerging electronic materials and devices (n)	
	Methods to enable lifetime prediction of MEMS devices (e/r)	
In fr as	Materials to enable resilient infrastructure components for hazard and disaster reduction (n)	In fr as tr

National Priority Area	Example Technology Priority Areas	MML Program Area(s)
	Methods to assess infrastructure condition to reduce repair cost and hazard (e/r)	
	Methods for assessing materials to enable prioritization of infrastructure repairs and reduce cost and hazard (e/r)	
	Failure analyses to improve materials selection and component design (e/r)	
	Materials to enable a sustainable infrastructure (n)	
	Materials to enable "Smart" structures to improve energy efficiency and security (n)	
Safety & Security	Improved methods to detect chemical, biological, radiological, nuclear, and explosive (CBRNE) threat materials (e/r)	Security, Safety, and Forensics
	Improved methods of materials forensics to enhance law enforcement (e/r)	
	Improved methods of materials screening to enhance aviation, rail, and cargo transportation security (n)	
	Materials to enable critical infrastructure protection from RNE threats (n)	

IV.b. *Future Customers*
Tables 7 and 8 list the six customer groups given in Table 3 and the industry sectors in Table 1 respectively. The tables include the relative level of the current MML effort (H, M, or L) and proposed future trends in the level of MML support (increasing ↑, decreasing ↓, or the same —) as determined from the external assessment and the team's knowledge of the customer groups.

Table 7. Current MML efforts and future trends by customer group

Customer Group	Current effort	Future Trend	Customer Group	Current effort	Future Trend
Developers	H	—	Users	M	—
Producers	H	↓	Recyclers	L	↑
Manufacturers	M	↑	Disposers	L	—

Table 8. Current MML efforts and future trends by industry sector

Industry Sector	Current effort	Future Trend	Industry Sector	Current effort	Future Trend
Automotive/Aviation	M	—	Food/Food Packaging	0	—
Building/Construction	M	—	Health and Beauty/Fashion	L	—
Consumer Goods	L	—	Materials	H	—
Electronics	H	↓	Medical Products & Equipment	M	↑
Energy	H	↑	Safety and Security	M	↑
Environmental	L	↑			

IV.c.*Future Customer Measurement Needs and NIST Measurement Solutions*
Future trends in the MML level of effort required to address each materials science measurement need listed in Table 3, based on the external assessment, are presented in Table 9, along with the current MML level of effort for each need. Materials science measurement solutions to address these needs were obtained from the external assessment; the eleven most common solutions are also presented in Table 9. The relevance of a measurement solution to a particular measurement need is indicated by the color of the cell: red (extremely relevant), orange (moderately relevant), yellow (weakly relevant) and white (no relevance). The future trends were determined by comparing the total number of relevant measurement solutions to the current MML level of effort. High priority measurement needs are in the areas of materials substitution, process optimization and control, and materials stability. The importance of a particular measurement solution is indicated by the same color scheme at the foot of the table. Prevalent measurement solutions are predictive modeling, measurements under relevant conditions, and standards and quality data.

Table 9. Measurement solutions mapped onto current MML measurement efforts

Measurement Needs	Current Effort	Future Trend	Predictive modeling	High throughput methods	Increased spatial resolution	Increased temporal resolution	Increased energy resolution	Relevant conditions	Real-time measurements	On-line monitoring	Standards and quality data	Sampling methods	Failure analysis	TOTAL
Materials discovery	M	↓												
Materials by design	L	↑												
Materials identification	H	–												
Materials optimization	H	–												
Materials substitution	M	↑												
Materials sustainability	L	↑												
Process optimization	H	–												
Process control	L	↑												
Regulatory compliance	M	↓												
Environmental impact	L	↑												
Materials selection	M	↓												
Materials integration	M	↓												
Reliability	M	↑												
Materials safety	L	–												
Materials stability	L	↑												
Release of materials from products	L	–												
Environmental remediation	L	–												
TOTAL														

V. *10 year Vision for Materials Measurement and Standards Programs in MML*
The data and analysis above points to a number of trends in industry and national measurement needs. These represent significant opportunities and emerging gaps that can guide the formation, growth and prioritization of future MML materials measurements and standards programs over the next 10 years. In summary:

- In the future, "downstream" needs in the materials product cycle will become increasingly important. These suggest that MML should turn its focus from measurement programs that support materials development and optimization in favor of programs that:
    - support manufacturing in priority technology sectors (see Table 6) through the development and dissemination of process monitoring and control measurement methods that enable high-volume fabrication of products incorporating advanced materials. Beyond simple sensors, the challenge is to create online measurements that bring the power of cutting-edge materials structure and properties measurements to the manufacturing line.
    - support the assessment and reduction of the environmental impact of materials by providing tools for environmental assessment under relevant conditions, and measurements that foster reduced use of toxic, critical and

energy intensive materials, through the use of materials substitutions and renewable or recycled feedstocks.

The first effort will support the Administration's emphasis on innovation and manufacturing, and the second will address the challenges associated with our Nation's inevitable and necessary shift towards sustainability.

- Nearly every sector roadmap examined called out the need for validated data and models for prediction of materials properties and reliability, especially for structural materials, advanced electronics and energy devices, and biomedical devices. Industry needs these validated data and predictive models to accelerate materials selection and the development of process designs to create products with optimal performance in a more cost effective manner. To address these needs, MML should leverage and shift its current analytical strengths in structure prediction towards models for properties prediction. For carefully chosen technology areas there is the opportunity to launch efforts to develop and demonstrate "materials by design", which represents a powerful combination of predictive modeling and materials property optimization. The external assessment suggests that advanced electronics and energy materials and physical infrastructure materials could be suitable targets for materials by design development. For predicting lifetime and reliability of materials systems, expertise in materials failure analysis should be enhanced. Overall, it is important that these measurements and models reflect relevant conditions, for example, pertinent environmental media, extreme conditions and manufacturing conditions.
- Because traditional electronics manufacturing has moved largely overseas, MML should reduce its emphasis on traditional semiconductor electronics. MML's extensive expertise and capabilities in this area can be redirected to address emerging measurement needs for renewable energy, and for the reliable manufacture of innovative advanced electronics devices, such as energy efficient electronics, flexible electronics, sustainable electronics and microelectromechanical systems (MEMS). In some cases, such transitions in MML programming have already begun.
- In the area of healthcare, our needs analysis suggests that MML program growth should focus on areas where the establishment of important new directions can be addressed by a strategic extension of current capabilities. For example, MML can establish a new effort in materials borne infection by leveraging and extending current expertise in dental materials. Generally, the needs identified in the area of biomaterials are natural extensions of currently existing programs. Accordingly, program redirection and refinement seems to be the appropriate method to address future measurement needs in biomaterials as they become prominent. Table 6 reflects the technology priorities in healthcare that emerged from the external assessment.
- Based on the analysis, future needs for many of the other materials-relevant technology areas can be accommodated by leveraging and redirecting current activities. For these areas, Table 6 reflects the technology priorities that emerged from the roadmap analyses.

V.a. *Future skill sets and expertise*

To address the future measurement trends, and achieve the 10 year Vision for Materials Science described above, MML will need to develop or acquire additional skill sets and expertise in:

- Predictive modeling of material properties and data evaluation methods. For targeted technology areas, skills and expertise in "materials by design" should see growth.
- Composition, structure and properties measurements under relevant conditions, including biological, environmental, manufacturing, and extreme conditions. Building such capabilities will likely involve developing a deeper expertise in assessing non-equilibrium materials structure and properties.
- Failure and stability analysis, and reliability engineering

V.b. *Future major facilities*

- Increased computational power to accommodate development and validation of predictive models
- Instruments that simulate relevant conditions including environmental assessments, measurements of manufacturing processes, extreme conditions and reliability
- A testbed for development of measurements methods for online monitoring of materials structure, composition and properties in manufacturing processes

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Appendix A: Definitions for Figure 2

Materials Science Customer Groups

- ***Developers***: suppliers of: new ideas for materials and their applications; new materials; or materials with optimized properties, *e.g.*, research and development labs at Corning, 3M, Du Pont, Reynolds
- ***Producers***: suppliers of commodity materials, *e.g.*, steel, concrete, polyethylene
- ***Manufacturers (products)***: suppliers of components, structures, devices, and systems produced or assembled from materials; may also produce materials as part of their manufacturing processes, *e.g.*, semiconductor device manufacturers
- ***Users***: users of products containing materials, *e.g.*, consumers, including industry, other agencies
- ***Recyclers***: collectors of used materials and manufacturers and suppliers of materials, components, and energy produced or assembled from used materials, including re-use of materials and components, *e.g.*, local councils, government agencies, corporations such as Alcoa, Dlubak Glass, RecycleIn America, Waste Management
- ***Disposers***: collectors of materials and components and transporters and storers of used materials and components, often with the intent of controlled degradation, *e.g.*, local councils, government agencies, corporations such as Waste Management

Activities: Measurement needs requiring NIST measurement solutions (C, S, P)[7]

- ***Material discovery***: finding a new material, with typically the goal of optimized properties (P)
- ***Materials by design***: developing and employing computational methods to combine known processing-structure-properties linkages of materials to select a composition and processing combination that produces a component with selected performance, *e.g.*, maximum load capacity per mass, minimum carbon footprint per cost (C, S, P)
- ***Material identification***: determining what a material is, typically by composition or structure (C, S)
- ***Material optimization***: developing processing methods that lead to materials with desired properties, typically using structure as the intermediate linkage (C, S, P)
- ***Material substitution***: developing or selecting a material to replace another, typically for health, safety, environmental, cost, business, or political reasons, *e.g.*, avoid sole supplier constraints, avoid dependence on other countries (C, S, P)
- ***Material sustainability***: selecting and recycling materials such that current and future needs (including energy and environmental) are met (C, S, P)
- ***Process optimization***: developing processing methods that lead to materials with desired structures, that enable cost-effective scale-up to production-level manufacturing, or that maintain desired structures at reduced processing cost (C, S, P)
- ***Process control***: maintaining a desired process, typically by monitoring materials structure and altering process parameters using known processing-structure linkages to regain the desired structure (C, S, P)

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[7] Composition (C), structure (S), property (P)

- ***Regulatory compliance***: using materials composition, structure, and property data to develop and enforce regulations to protect humans and the environment (C, S, P)
- ***Environmental impact***: using materials or product composition, structure, and property data in relevant media to determine and predict potential adverse effects of materials and products on the environment (C, S, P)
- ***Material selection***: employing materials properties databases, *e.g.*, Cambridge Engineering Materials Selector, to choose a material for a particular application such that component or system performance is optimized, *e.g.*, selecting an insulating material for greatest energy efficiency of a kiln (P)
- ***Materials integration***: selecting processing or manufacturing methods such that different materials can be combined (integrated) into components or devices such that manufacturing yield or operational performance (especially reliability) is maximized, *e.g.*, limiting subsequent thermal excursions after thin films with different coefficients of thermal expansion are deposited in a microelectronic device (C, S, P)
- ***Reliability***: Selecting processes or materials that generate structures or properties such that components or devices exhibit required performance, *i.e.*, avoid failure, over required lifetime, *e.g.*, selecting a glass with stable color centers such that window transparency is maintained over the life of a building; could also involve the prediction of lifetime from knowledge of failure mechanisms (C, S, P)
- ***Material safety:*** using materials composition, structure, and property data to determine or predict potential adverse effects of materials and products on human health (C, S, P)
- ***Material stability***: selecting a material with invariant properties, dimensions, or composition on environmental exposure, *e.g.*, a radiation resistant steel, a water resistant concrete, a temperature resistant silicone; or with a controlled or desired variation, *e.g.*, a sacrificial anode, a soluble pharmaceutical, a foamable gel; could also involve the prediction of stability from knowledge of environmental interaction mechanisms (C, S, P)
- ***Release of materials from products:*** using materials composition and structure data to determine or predict the release of materials from products (C, S)
- ***Environmental remediation:*** using materials composition, structure, and property data to develop approaches that utilize materials for the removal of pollution or contaminants from the environment, or to remediate or abate materials that pollute or contaminate the environment (C, S, P)